THE UTILISATION OF LOW-GRADE AND WASTE FUEL

W. F. GOODRICH

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BY

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"PULVERISED FUEL," "MODERN DESTRUCTOR PRACTICE,"
"REFUSE DISPOSAL AND POWER PRODUCTION,"
ETC., ETC.

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PREFACE

WITHIN the past few years many fuels which had been generally regarded as worthless, unsatisfactory or unsaleable, either because of their low calorific value, high ash or moisture content, size, or for other reasons, are now being efficiently utilised in increasing quantities. For instance, only a few years since coke breeze was to a large extent unsaleable—it may, in fact, be said that its value for steam generation received but tardy recognition, and it has only been removed from the category of waste fuels as the result of stringent fuel conditions and high prices.

During the period of Coal Control, and particularly at the time when an increasing demand for fuel synchronised with a decreasing output of coal, it was conclusively demonstrated that many low grade and waste fuels could be efficiently utilised for steam generation and for other purposes.

The striking increase in the utilisation of low grade and waste fuels within recent years may be attributed to various reasons, not the least important of which are economic. High coal prices, heavy freight charges, reduced output, and consequent shortage have been responsible for a marked increase in the consumption of low grade and waste fuels in Great Britain, and in other countries.

In some European countries and also in Australia, for the same or similar reasons, a great impetus has been given to the development of available low grade high moisture fuels, such as peat, lignite, and brown coal.

There are distinct signs that this development is not merely spasmodic or transient, but that it will steadily continue. In Denmark and Italy the output and use of peat has increased considerably, as has also the production and use of lignite and brown coal in Germany, Italy, and Czecho Slovakia. So rapidly is the output of lignite increasing in Germany that within the next few years it is certain to considerably exceed the production of coal.

The very important brown coal developments at Morwell (Victoria), Australia, may be said to be directly due to two reasons:—(1) The frequent shortage of imported coal supplies and their high cost, and (2) the determination to foster industrial expansion by providing an ample and cheap supply of electric energy for power purposes, utilising on the coal field a very cheaply mined fuel, which in its raw state must, by reason of its high moisture content, be regarded as a low grade fuel. One very important factor in the utilisation of the lower grade and waste fuels has been the marked improvement in furnace design and the close attention which has been devoted to the design of machine-fired furnaces, with the practical elimination of manual labour both in the handling of fuel and ash.

In Canada for several years past exhaustive and valuable research and experimental work with lignite has been proceeding. The development of the immense lignite deposits of Western Canada is essential if a large section of the Dominion is to become independent of expensive imported coal.

An American writer has termed lignite "the fuel of the future." Taking a long view there is much truth in this observation, bearing in mind that about one-third of the coal reserves of the United States are lignite.

While this is true of the United States, it is equally true in so far as the coal reserves of many other countries are concerned.

Although the use of fuel in pulverised form does not come within the scope of this work, there can be no doubt that with the successful development of this system of firing it will be possible to utilise a considerable range of fuels which are now to a large extent regarded as useless.

Coal dust, sweepings, smudge and washery settlings, if air dried and the moisture reduced to from 5 to 8 per cent., may thus be utilised for steam generation with an evaporative output and a thermal efficiency which is impossible with any other system of firing.

The possibilities of pulverised fuel firing are such that the future accumulations at collieries should be confined entirely to bats and pickings, which by reason of the embedded condition of the combustible, and the high percentage of incombustible, are to a large extent commercially unuseable.

To many friends at home and abroad who have kindly furnished much useful data and information, and to others in British dominions and elsewhere overseas who so willingly granted facilities for inspection and investigation, the Author desires to tender his sincere thanks.

W. F. G.

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THE UTILISATION OF LOW GRADE AND WASTE FUELS

CHAPTER I

THE UTILISATION OF WASTE FUELS AND COAL CONSERVATION

"EVERY basket is power and civilisation.[1] For coal is a portable climate. It carries the heat of the tropics to Labrador and the Polar circle, and it is the means of transporting itself whithersoever it is wanted. Watt and Stephenson whispered in the ear of mankind their secret, that half an ounce of coal will draw two tons a mile, and coal carries coal by rail and boat, to make Canada as warm as Calcutta, and with its comfort brings its industrial power."

The efficient utilisation of waste and low grade fuels, and the elimination of all avoidable loss by making the fullest possible use of all combustible, so far as may be commercially practicable, have a direct and important bearing upon conservation, the necessity of which has not yet been fully realised.

The conservation of coal is a many-sided and complex problem, the solution of which will not be found in the generally efficient use of the higher grade fuels alone, vitally important as this is.

In Technical Paper No. 123,[2] entitled "Notes on the Use of Low Grade Fuel in Europe," by R. H. Fernald, issued by the United States Bureau of Mines, the author thus refers to the conditions in the United States :—

"A careless indifference to efficient utilisation, due in great measure to the abundance of our resources, have led us to neglect far too long the serious consideration of problems upon which hinge many of the possible activities of future generations.

"The unrestricted use of our better grade fuels, and the ruthless waste and neglect of fuels that should be of real commercial value, are phases of our national extravagance that are little short of appalling."

It may be assumed that this fairly described the conditions obtaining in the United States eight years since, conditions which to a very large extent remain unchanged. It may be further observed that Mr Fernald's criticism very accurately describes the conditions which obtain in Great Britain at the present time.

[1] See Emerson on "The Power of Coal."

[2] "Notes on the Use of Low Grade Fuel in Europe," by R. H. Fernald. Technical Paper No. 123, Department of the Interior, Bureau of Mines, 1915.

Coal has been termed "the basic foundation of our civilisation," the material foundation of all industry, and our most valuable natural asset. In any consideration of the utilisation of low grade and waste fuels it is desirable to review our present position as a coal-producing country, in comparison with that of other coal-producing countries, particularly from the point of view of our reserves, our present inefficient methods of use, and our failure generally to apply the elementary principles of conservation.

To a very large extent coal is still used as though the supplies were inexhaustible, and the cost immaterial. It must at the same time be frankly conceded that owing to conditions brought about as the result of the war, much more interest than hitherto has been evinced in questions of fuel economy, but to a serious degree this interest has been merely transient, and it would be idle to state that the position generally at this time shows any very marked advance or improvement upon the conditions which obtained ten years since.

The present position is that from the point of production—the colliery—throughout our industries, with the solitary exception of the carbonisation industries only, and also in our homes, the waste of fuel from the best grades to the most inferior grades is widespread and enormous. Professor Vivian B. Lewes, F.I.C., F.C.S.,[1] thus referred to the waste of fuel in this country only a few years since :—Our waste of solid fuel has been a disgrace to us as a civilised nation, but it is a waste in consumption brought about by improper methods of use, and selfish disregard of what the future might bring forth for others."

It is scarcely necessary to observe that during the few years which have passed since the above opinion was expressed, the cost of coal has increased very considerably, nevertheless it must be admitted that our waste of solid fuel is still a disgrace to us as a civilised nation, that improper methods of use to a very large extent still obtain, and that, generally speaking, we are no more concerned with the fuel problems of posterity than with the present insistent need for efficiency.

In his evidence before the Coal Industry Commission in 1919,[2] Sir Richard A. S. Redmayne, K.C.B., made the following observations :—

" . . . Science is not brought to bear upon the consumption of fuel to anything like the extent it should be, and we are extraordinarily ignorant as a nation as to the quality of coal that exists in the country. We have actually to go to Sweden to find the best work on the quality of British coal.

"I have found during the time I have been on the Coal Exports Committee that the foreigner has a better knowledge of the qualities of British coal than the ordinary British consumer."

Questioned thus by Sir Adam Nimmo :—" Does it not amount to this, that it is the consumer in this country who requires to be stirred up, more than the coal owner ? " Sir Richard Redmayne replied :—" I think they both want stirring up."

Those who have been concerned with steam generation and fuel problems in

[1] " Oil Fuel," by Professor Vivian B. Lewes, F.I.C., F.C.S. (page 227).

[2] Report of the Coal Industry Commission, vol. xi., 1919.

this country will emphatically endorse Sir Richard Redmayne's opinion, that both those who own and produce coal and those who use it want stirring up.

Mr H. C. Hoover referring to the bituminous coal industry in the United States is reported to have said that "the industry was the worst functioning of all industries."

While not desiring to go so far as to suggest that this observation may be fairly applied to the coal industry in Great Britain, it may nevertheless be stated that the scope for economy at collieries is enormous, and the extent of the preventible waste is both very serious and widespread.

If the colliery industry generally were conducted with a view to the conservation of coal it would be the general rule to utilise at the point of production the lower grades of unsaleable fuel, thus releasing for the market the maximum percentage of the total saleable output.

There are collieries operated upon such lines, but there are others—and they are not a few—where these conditions do not obtain. Not only are grades of fuel burned which should be available for revenue production, but consequent upon the use of antiquated and uneconomical steam plant the consumption is excessive.

The waste at collieries is by no means confined to the inefficient use of coal and steam, the various reports of the Royal Commissions have all directed attention to the serious waste in its several phases.

In a paper read before the South Wales Institute of Engineers in 1918 by Mr W. T. Lane,[1] the waste and loss at collieries were thus referred to :—

"During the past some hundreds of millions of tons of valuable small coal have been deliberately lost. The immediate prevention of this suicidal process of waste is essential, and should be prevented by the introduction of legislation."

Waste at collieries has not escaped the notice of Mr Frank Hodges, who, in his work entitled "Nationalisation of the Mines," [2] states that annually "small coal to the extent of $2\frac{1}{4}$ million tons is lost through the use of inadequate machinery for separating it from the rubbish and refuse at the surface, inefficient methods of working, and water logging."

In the Final Report of the Coal Conservation Committee, under the heading "Loss through small coal cast back underground," the following information is given :—

The information [3] thus obtained shows that the only coalfields in which a substantial loss from the above cause is at present taking place are :—

Nottinghamshire and South Derbyshire.
Leicestershire and South Derbyshire.
Warwickshire.
South Wales.

[1] "Fuel Economy and Power Production," by W. T. Lane. *Proceedings of the South Wales Institute of Engineers*, 1918.

[2] "Nationalisation of the Mines," by Frank Hodges (page 36).

[3] Coal Conservation Committee Final Report, 1918 (page 52).

In the remaining coalfields little or no loss appears to be taking place, all the small coal which it seems in any way practicable to save being brought to bank.

Generally it appears that the total approximate quantity of small coal cast back in the coalfields of Great Britain at the present time is 2,325,000 tons per annum, as shown in the following summary :—

Coalfields.	Tons.
Nottinghamshire and South Derbyshire	574,000
Leicestershire and South Derbyshire	184,000
Warwickshire	65,000
South Wales	1,502,000
	2,325,000

As indicative of the waste in industrial fuel consumption the following extract from the Report of the Fuel Research Board for 1918-1919 will be of interest ; it is quoted because it so completely and strikingly confirms the frequently expressed opinions of many engineers, who have been in close touch with the utilisation of coal for steam generation and other industrial purposes :—

". . . It follows [1] from these considerations that in any practical programme for fuel economy, the first place ought to be assigned to the putting in order by the consumers themselves of a system of control which will ensure that a stop shall be put to gross waste, and that the existing appliances and known methods are worked to the best advantage. There is no doubt that in the majority of industrial undertakings a reduction of from 5 per cent. to 20 per cent. could be secured within a year at a relatively trifling expenditure on wages, and small alterations of apparatus. In one case known to us a saving of 30 per cent. on the fuel consumption was effected during the past year, merely by the application of more perfect control."

It cannot be too strongly or too frequently emphasised that preventible fuel waste represents a collossal direct tax upon industry, a tax which, unlike other taxes under which industry groans, is self-imposed, and which may be and should be removed, not only in the interests of the individual and the industry, but in the wider interests of the nation.

Avoidable waste due to inefficient use is not confined to this country and the United States, it is found in almost every country without exception. The steps which have been and are being taken to combat waste furnish in themselves very conclusive evidence not only that wasteful conditions are general, but also that the imperative need for conservation is now generally recognised and conceded.

In Canada a Commission of Conservation has been actively working for some years past. In France a company subsidised by the French Government (L'Office Central de Chauffé Rationale de Paris) assists steam users, provides training for men, and conducts research work.

[1] Report of the Fuel Research Board, 1918-1919 (page 5, No. 19).

There is much activity in Germany, colliery consumption, carbonisation of coal and lignite, and the utilisation of low grade fuels, illustrate the scope of operations of the Fuel Research and Utilisation Committee of the Advisory Council. Even in the smaller European countries, having but a comparatively insignificant coal consumption, conservation is receiving very serious attention.

In Denmark, for instance, the Dansk Braendsels-og-Kontrolforening (Danish Association for the Control of Fuel), established in 1918 has done very useful work in the promotion of fuel economy.

This Association, which is maintained partially by subscribers and partially by a state Subsidy, carries out investigations, makes suggestions for economy in the use of fuel, and undertakes staff training.

At Prague, Czecho Slovakia, an "Institute for the Economic Use of Fuel" has been established by a Government ordinance. Its operations will cover the whole of the Republic, and are defined as "the systematic investigation of fuel, and the places of its deposit, with their development."

In Holland there are three organisations actively concerned with the efficient use of fuel. The Vereeniging tot Bevordering van Rookrij Stoken (Association for the Improvement of Smokeless Firing), founded in 1908; The Vereeniging van Gebruikers van Stoomketels en Krachtwerktingen (Association of Users of Steam Boilers and Power Plant), established in 1915; and The Bureau voor Warmte en Krachteconomie (Bureau of Heat and Power Economy), founded by Royal Decree in 1921.

These Associations undertake plant investigation, evaporative tests, suggest improvements in operation and control, also in the methods of recording technical data: the object being the maintenance of plant at a high standard of efficiency.

In France an Inter-ministerial Commission has been instituted by decree, the function of which will be to centralise all investigation and research work relating to fuel production, and to increase the production of coal, peat, lignite, etc., in France and French possessions.

In the United States, all fuel problems are being investigated by the Bureau of Mines. The scope for conservation was thus expressed by David Moffat Myres, who did such valuable work in the promotion of fuel economy during the war:—

"If all the well-known and well-tried methods of fuel conservation were put into effect throughout the United States, the resultant saving would amount to 75 to 100 million tons of coal per year, without reference to the saving that could be effected in the use of other fuels. If those engineers who know what to do and how to do it, were turned loose with a free hand, this would be the result."

In England H.M. Fuel Research Board is engaged in investigation and research work, the nature and scope of which cannot but be of immense value to the nation.

Despite all that has and is being done waste and inefficiency are still general. In those countries producing little or no coal, and having to rely mainly upon imported coal, there would appear to be little doubt that much closer attention is

being devoted to questions of fuel economy than hitherto, but in the great coal-producing countries the process of education is slow, the "coal conscience" has not been awakened, and there would appear to be no widespread determination or effort to efficiently utilise the higher grades of fuel, or to make an extensive use of low grade fuels. In short, we have yet to see any real determination to grapple with the problems of conservation upon a scale at all commensurate with their importance and urgency.

Not only is coal our most valuable natural asset, but it is a diminishing or wasting asset. Even were all done which might be done along proved lines of conservation, we should still be face to face with the fact that our coal resources are being steadily depleted.

The Royal Commission of 1866 reported that the available coal in proved areas at less than 4000 feet in depth was about 90,000 million tons; further, that in other unproved areas 56,000 million tons was available.

The Royal Commission of 1901 reported the available quantity to be approximately 101,000 million tons of proved coal, and about 39,000 million tons in unproved areas, also that at depths in excess of 4000 feet some 5200 million tons was available.

In 1912 Dr Straham, the eminent geologist, estimated the available tonnage within 4000 feet of the surface as 178,727 million tons, while three years later Professor H. S. Jevons estimated the available tonnage as 197,000 million tons.

Interesting as these figures are the vital question is not how much coal is available at any depth or in any location, but rather how much useable coal is available which can be mined at an economic cost, such a cost in fact as will enable us to successfully compete with other coal-producing and industrial countries.

The following data showing the output of coal in the chief producing countries of the world for the years 1919 and 1920 have been extracted from the Report of the United States Geological Survey, dated April 9th, 1921 :—

	1919. Tons.	1920. Tons.
Canada	9,756,019	15,080,597
United States	495,460,893	585,732,560
Austria	89,744	133,173
Belgium	18,342,950	22,413,535
Czecho Slovak Republic	10,384,800	11,130,800 coal
	17,110,500	19,695,500 lignite
France	21,546,000	24,300,000
Germany	116,500,000	140,757,433 coal [1]
,,	93,800,000	111,634,000 lignite
Spain	3,901,637	5,367,625
Spitzbergen [2]	88,776	170,000

[1] Includes Saar Basin, 1919=8,990,000 tons; 1920=9,410,433 tons. [2] Incomplete data.

	1919. Tons.	1920. Tons.
United Kingdom	233,467,478	232,975,000
Japan	30,236,000	31,000,000 [1]
South Africa	9,313,232	11,181,846

Less than half a century ago we were producing nearly one-half of the world's total output. Our comparative output in 1875 and in 1920,[2] as also the output in the United States and Germany for the corresponding periods, are here given :—

	1875. Tons.	1920. Tons.
United Kingdom . . .	133,300,000	232,975,000
United States . . .	46,700,000	585,732,560
Germany	47,800,000	252,391,433

In 1870 the output of British collieries was about 110 million tons, forty years later the output had increased to 264·4 million tons. Since 1910 the annual output has been as follows :—

1911	271·9 million tons.
1912	260·4 ,,
1913	287·4 ,,
1914	265·7 ,,
1915	253·2 ,,
1916	256·4 ,,
1917	248·5 ,,
1918	226·5 ,,
1919	229·2 ,,
1920	232·9 ,,

It is not within the scope of this work to discuss the reasons why the output of 1913 has not been maintained. In so far as the case for the miners is concerned, this has been very ably presented by Mr Frank Hodges in his work entitled, "Nationalisation of the Mines." [3] It is a matter for regret that the case for the mine owners has not been put with at least equal clearness.

The above figures have been included only with a view to showing the reduced and fluctuating output during a period when the output in the United States has been rapidly increasing.

In order to clearly appreciate the comparative position in Great Britain in regard to available coal reserves, it is desirable to compare the extent of our reserves with those of other coal-producing countries, in so far as these reserves have been determined.

[1] Incomplete data.
[2] The total output throughout the world in 1875 was 277,700,000 tons.
[3] "Nationalisation of the Mines," by Frank Hodges.

The actual and probable coal reserves within the British Empire are as follows :—

	Millions of Tons. Metric.
Great Britain and Ireland	189,533
Canada	1,234,269
Newfoundland	500
Australia	167,572
New Zealand	3,386
British North Borneo	75
India	79,001
Africa	56,579
	1,730,915

From the above figures it will be clear that the available coal reserves in Great Britain and Ireland are rather in excess of 10 per cent. of the total available reserves within the British Empire.

Taking for comparison those countries possessing the greatest reserves, viz., the United States, Germany (pre-war), and China, the comparative figures are :—

	Millions of Tons. Metric.
United States	3,838,657
Germany	423,356
China	995,587

Comparing Great Britain and Ireland with these three countries, it is shown that our actual and probable coal reserves are in the following percentages :—

To the United States	4·94 per cent.
,, Germany	44·77 ,,
,, China	19·04 ,,

As compared with the actual and probable coal reserves in *all* producing countries our percentage is only 2·56 per cent.

It is interesting, if not consoling, to compare the percentages of the total reserves of all the producing countries of the world held by Great Britain, the United States, Germany and China :—

Great Britain	2·56 per cent.
United States [1]	51·88 ,,
Germany	5·72 ,,
China	13·46 ,,

The United States, China, and also probably Germany will, it is evident, be possessed of ample coal reserves long after Great Britain has ceased to be a coal-producing country.

It is true that this period is probably a few centuries ahead ; and while it may

[1] Approximately one-third is lignite.

be argued that we should not concern ourselves with the problems of posterity, yet it may at least with equal fairness be argued that we in our time have no right to waste the basic commodity of industry, with an utter disregard for the claims of future generations.

Especially should it be borne in mind that we are wasting an asset which we have done nothing to produce, and which we can do nothing to recreate.

The various comparative figures of coal reserves which have been quoted are total figures, including in all countries not only the higher grade fuels but also all reserves, actual and probable, of sub-bituminous coal, brown coal, and lignite.

The importance of developing and utilising these and other available low grade fuels, which has been so frequently emphasised by many authorities, is at once apparent when it is borne in mind that within the British Empire the percentage of sub-bituminous coal, brown coal, and lignite is no less than 57·04 per cent. of the total actual and probable coal reserves, while in other countries these lower grade fuels represent 35·45 per cent. of the total coal reserves.

The term sub-bituminous, which is now commonly used, was adopted by the United States Geological Survey for fuels which had frequently been called "black lignite," an incorrect term, inasmuch as the coal is usually free from any trace of woody structure.

It is somewhat difficult to separate this class from the bituminous fuels on the one hand, and lignites on the other, although it is usually distinguished from the latter by its colour and freedom from apparent woody structure, and from the former by its tendency to disintegrate and slack upon exposure.

The term lignite, as used by the United States Geological Survey, is restricted to coals that are distinctly brown in colour, and usually of a woody texture.

Some analyses of typical United States sub-bituminous coals are here given :—

TABLE No. 1

Proximate Analysis. *Ultimate Analysis.*

	Moisture.	Volatile Content.	Fixed Carbon	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	B.T.U.
Simpson, Colorado	18·68	34·88	40·05	5·99	·55	6·07	57·46	1·15	28·78	10,143
Red Lodge, Montana	11·05	35·90	42·08	10·97	1·73	5·37	59·08	1·33	21·52	10,539
Gallup, New Mexico	10·79	33·82	36·73	18·66	1·26	5·22	55·07	·95	18·84	9,907
Renton, Washington	14·30	33·03	41·30	11·37	·72	5·73	57·27	1·17	23·74	10,208
Coal Creek, Washington .	12·05	36·82	40·72	10·41	·34	5·75	58·15	1·37	23·98	10,414
Hanna, Wyoming .	11·30	40·32	41·07	7·31	·28	5·56	61·24	·88	24·73	10,755
Monarch, Wyoming	22·63	35·68	37·19	4·50	·59	6·39	54·91	1·02	32·59	9,734

The following figures are an estimate of the actual and probable coal reserves of the British Empire and other countries in millions of tons (metric), comprising *sub-bituminous coal, brown coal, and lignite only.*

TABLE No. 2

	Actual Reserves.	Probable Reserves.	Total.
BRITISH EMPIRE—			
Great Britain and Ireland	..	..	..
Canada	384,968	563,482	948,450
Newfoundland	..	..	..
Australia	219	32,414	32,633
New Zealand	612	1,863	2,475
British North Borneo	..	..	..
India	225	2,377	2,602
Africa	74	..	74
	386,098	600,136	986,234
OTHER COUNTRIES—			
United States	..	1,863,452	1,863,452
Germany	9,313	4,068	13,381
Austria-Hungary	12,585	1,913	14,498
France	301	1,331	1,632
Belgium	..	..	..
Russia	12	1,646	1,658
Spain	394	373	767
Spitzbergen	..	..	..
Bosnia and Herzegovina	1,700	1,976	3,676
Netherlands	..	..	..
China	..	600	600
Japan	67	711	778
Manchuria, Siberia	..	107,844	107,844
Indo-China	..	..	..
Nertherland India	734	337	1,071
Persia	..	..	..
	25,106	1,984,251	2,009,357

Upon referring to the foregoing tabulated figures it will be observed that there are no reserves of these particular low grade fuels in Great Britain and Ireland, which only serves to emphasise the necessity for devoting close attention to the utilisation of the various lower grade and waste fuels which are available, which are now to a serious extent neglected, and which will be discussed in succeeding chapters.

In an article in *The Edinburgh Review*, Professor John W. Cobb, C.B.E., B.Sc., Livesey Professor of Coal Gas and Fuel Industries at Leeds University, referred thus to the question of coal and its cost :—

" The position,[1] apparently, is that we may count with some certainty upon a steady and perhaps increasing supply of dear coal, but that the cheap coal, upon which the manufacturing methods and complicated organisation of many of our industries has been based, is to be counted as a thing of the past."

This may be said to accurately represent the present position. There is no indication of any relief in the form of cheap coal for industrial purposes. From the point of view of conservation this is scarcely a matter for regret, having in mind that the high cost of coal, far more than any other factor, has to a certain extent enforced increasing economy in its use, whereas when coal was cheap it was wasted to a greater extent than at present.

Even if it were possible to at once reduce the average price of various grades of industrial coal to the extent of 25 per cent., this would in no way beneficially affect questions of inefficiency and waste. On the contrary, cheap coal would tend to promote and encourage waste and inefficiency, as it invariably has done in the past.

It is not anticipated that there can be or will be any substantial decrease in the cost of coal. The existing condition of the coal industry is such as not to encourage hope in this direction. The present problem is to eliminate all avoidable waste under such conditions as obtain. To this end it is imperative that low grade and waste fuels should be utilised so far as may be practicable at or adjacent to the point of production.

[1] "Coal and Smoke," by Professor John W. Cobb, C.B.E., B.Sc., F.J.C. *The Edinburgh Review*, October 1921.

CHAPTER II

THE UTILISATION OF COLLIERY WASTE FOR STEAM GENERATION

UNDER the category of waste fuels at collieries may be placed a considerable range of fuels comprising what are known in the various coal-fields as Duff, Gum, Smudge, Slurry Culm, Dant, Pond Tank or Washery Settlings, Fines, Breeze, Ballast, Bats, Pickings, etc.

These fuels vary considerably in calorific value, and ash and moisture content. Some are partially or entirely utilised at collieries or sold, others are banked or heaped, and are regarded more or less as unsaleable waste.

While there has been and still is an increasing tendency to utilise at collieries fuels for which there is but little if any commercial demand, thus releasing for the market the maximum proportion of the output of better grades of coal, this is by no means the established practice.

Owing to the antiquated equipment of many collieries, in so far as the steam power plant is concerned, it is in many cases not possible to utilise the lower grades of fuel for steam generation. Under such conditions from 6 per cent. to 15 per cent. of the total output which might be sold is used, and fuel which should be utilised is instead to a large extent tipped to waste. When the author gave evidence before The Royal Commission on Coal Supplies (1904), particularly concerning the utilisation of low grade fuels, he submitted the following Table (No. 3),[1] showing the analyses of certain waste fuels, some of which were then being partially utilised for steam generation.

These analyses have not been included because they possess any present interest or value, but merely for convenient comparison with a number of analyses of a variety of waste fuels, which have all been made within the past two years, and which are included in Table No. 4.

The analyses in Table No. 4 cover a wide range of fuels, many of which have been regarded as waste fuels, for which there has been little or no commercial demand.

Some of the very low grade fuels included in this Table, as, for instance, bats and pickings, owing to their high ash content, and the labour involved in separating the combustible from the incombustible, may be generally regarded as useless.

Many of the washery residues are difficult to deal with, but assuming that

[1] Second Report of the Royal Commission on Coal Supplies, vol. xi., Minutes of Evidence, 1904.

the ash content is within reasonable limits, there should be no difficulty in considerably reducing the moisture content by air drying.

During the war a considerable number of pit heaps were surveyed. In some cases the waste fuel was freshly wrought, in many other cases heaps had been standing for upwards of fifty years, such accumulations usually being at or adjacent to " worked out " or abandoned pits. A large number of samples were taken for analysis, when it was found that quite a considerable proportion could be utilised.

It is only fair to observe that many of these large deposits of low grade fuel were accumulated at a time when all fuel was cheap, and the fuels then tipped to waste were unsaleable.

TABLE No. 3

		Calorific value evaporation per lb. of fuel from and at 212° Fahr.	Volatile matter.	Incombustible.	Moisture.
Park Coal Company, Mirfield	Coke dust and coal dust	10·2	22·96	22·23	..
Nunnery Colliery Co., Sheffield	Pond settlings from tip	10·3	27·43	16·06	..
Low Moor Co., Ltd., Bradford	Tank settlings .	5·75	20·63	20·66	10·5
Aldwarke Main Colliery, Rotherham	Pickings . .	10·8	35·5	24·066	..
Morley Main Colliery Co.	Bottom hub .	7·1	41·6	42·0	..
Nunnery Colliery Co., Sheffield	Pickings from screens	8·5	24·075	36·6	..
,, ,,	Washery refuse .	5·1	17·125	54·66	..
,, ,,	Pickings . .	13·0	35·16	9·23	..
Fryston Colliery Co. .	Fine washings .	8·19	39·36	38·9	..
New Sharlston Colliery, Normanton	Washery refuse .	10·28	..	11·3	11·4
,, ,,	Pond settlings .	12·04	..	0·78	40·2
Woolley Colliery Co. .	,, .	11·66	21·125	17·4	..
Crawshaw & Warburton, Dewsbury	Shale . . .	4·45	27·03	56·63	..

In Table No. 5 are included a series of evaporative tests at collieries with Lancashire boilers, both machine fired and hand fired, burning a variety of low grade and waste fuels.

TABLE No. 4

Low Grade Fuels in Colliery Areas

District.	Description.	Fixed carbon.	Volatile matter.	Ash.	Moisture.	Calorific value B.T.U.'s.
1. South Staffordshire	Smudge	39·28	15·7	24·41	*21·24	6,884
2. West Yorkshire	,,	54·79	16·41	23·21	5·49	9,653
3. South Yorkshire	,,	40·31	22·27	24·26	13·16	8,566
4. North Staffordshire	,,	27·81	11·66	*34·31	*26·17	4,524
5. South Yorkshire	Slurry	49·76	19·07	9·72	*21·49	9,647
6. Derbyshire	,,	39·62	15·49	19·06	*25·86	7,163
7. Nottingham	,,	37·69	13·46	19·96	*28·91	6,265
8. South Yorkshire	Washery silt	36·47	17·11	21·09	*25·38	7,141
9. Lancashire	,, settlings	46·63	23·96	*27·18	2·27	10,607
10. South Yorkshire	,, settlings	52·49	20·87	10·53	*16·17	10,243
11. Derbyshire	,, waste	46·92	17·61	16·43	*19·08	9,176
12. Warwickshire	,, settlings	34·75	21·28	20·69	*23·32	7,212
13. South Staffordshire	,, settlings	45·42	22·14	23·24	12·28	8,654
14. North Staffordshire	,, finings	38·41	19·49	*32·91	10·53	7,503
15. Lancashire	,, settlings	48·06	19·28	22·57	10·19	9,426
16. North Staffordshire	Heap waste	38·59	22·79	*37·34	2·34	8,087
17. South Staffordshire	Pit tip	39·06	30·16	18·61	12·16	9,677
18. Lancashire	Pit heap waste	39·67	27·42	*30·44	2·69	8,952
19. Worcestershire	Mound siftings	38·21	28·49	22·89	11·61	8,669
20. ,,	Mound waste	37·86	25·76	24·44	11·96	7,988
21. South Staffordshire	Fine tip slack	45·51	25·10	17·11	12·36	8,829
22. North Staffordshire	Tip waste	47·49	24·67	18·72	9·18	9,307
23. Warwickshire	Heap slack	42·56	29·94	12·33	*15·25	8,834
24. ,,	Bats	37·39	29·00	*25·91	7·60	8,691
25. Leicestershire	,,	27·23	24·79	*40·08	8·02	6,548
26. Derbyshire	,,	50·69	25·46	18·51	5·42	10,537
27. Leicestershire	Pickings	23·32	24·71	*44·73	8·01	8,722
28. North Staffordshire	,,	33·29	19·46	*46·19	1·30	8,631
29. Derbyshire	,,	35·43	24·22	*36·78	4·01	8,247
30. North Staffordshire	,,	47·89	27·34	21·53	3·26	10,484
31. Leicestershire	Screened dust	49·17	26·75	14·82	10·35	9,854
32. Warwickshire	,,	48·76	30·29	9·16	11·61	10,319
33. Nottingham	,,	36·69	21·64	23·56	*18·36	7,892
34. Lancashire	Dant	49·41	25·85	22·23	2·51	10,698
35. Glamorgan	Bank small	64·65	13·86	20·12	1·38	11,727
36. ,,	,,	71·57	14·13	12·58	1·71	12,762
37. ,,	Steam duff	65·96	10·82	20·91	2·32	11,018
38. ,,	Unwashed duff	65·62	11·49	21·16	1·85	11,371
39. Ayrshire	Dry gum	45·82	28·86	18·13	7·19	10,617
40. Fifeshire	,,	55·01	30·71	9·36	..	12,118
41. Derbyshire	Coke dust	48·98	4·22	15·29	11·49	10,176
42. North Staffordshire	Coke breeze	61·66	9·43	15·66	10·31	10·118
43. ,, ,,	Tip breeze	66·72	10·08	12·78	10·53	10,654
44. ,, ,,	Fine tip breeze	49·97	8·84	*36·02	5·26	8,149
45. Glamorgan	Coke breeze	63·27	5·78	16·12	14·81	9,528
46. South Yorkshire	,, breeze	65·75	7·86	15·64	10·82	10,257
47. Derbyshire	,, dust	63·89	14·63	13·54	7·96	11,336
48. West Yorkshire	,, ballast	76·91	2·98	18·61	1·42	11,193
49. North Staffordshire	,, breeze	66·46	4·56	*27·88	1·16	10,352
50. ,, ,,	Fine breeze	61·03	10·01	*26·07	2·92	9,715

* Fuels marked * containing upwards of 25 per cent. of ash or 15 per cent. of moisture have generally been regarded as of doubtful commercial value, although the moisture content of washery waste could be considerably reduced by air drying.

TABLE No. 5

Evaporative Tests at Collieries with Low Grade Fuels

	1. Derbyshire.	2. Staffordshire.	3. Gloucestershire.	4. Derbyshire.	5. Yorkshire.	6. Durham. (a)	6. Durham. (b)
System of firing	Bennis sprinkler stoker and compressed air furnace	Bennis sprinkler stoker and compressed air furnace	Bennis sprinkler stoker and compressed air furnace	Bennis sprinkler stoker and compressed air furnace	Bennis *hand-fired* compressed air furnace	Bennis *hand-fired* furnace	compressed air
Date of test	March 5th, 1923	Nov. 30th, 1922	Feb. 16th, 1922	April 17th, 1923	Jan. 23rd, 1923	July 17th, 1922	
Duration of test	6 hours	7 hours	8 hours	7·25 hours	6 hours	4 hours	3 hours
PARTICULARS OF BOILERS USED—							
Number of boilers	2	1	1	1	1	1	1
Type of boilers	Lancashire	Lancashire	Lancashire	Lancashire	Lancashire	Lancashire	Lancashire
Size of boilers	30′×8′	30′×8′	30′×8′ 6″	30′×8′ 6″	30′×8′ 6″	30′×8′	30′×8′
Heating surface of each boiler	998 sq. ft.	998 sq. ft.	1,084 sq. ft.	1,084 sq. ft.	998 sq. ft.	998 sq. ft.	998 sq. ft.
Grate surface of each boiler	36 ,,	38 ,,	40 ,,	40 ,,	42 ,,	41 ,,	41 ,,
Ratio of heating surface to grate surface	..	26·26 to 1	27·1 to 1	27·1 to 1	23·7 to 1	24·34 to 1	24·34 to 1
Nature of draught—natural, forced, or induced	Natural	Natural	Induced	Natural	Natural	Natural	Natural
Type of mechanical firing apparatus (if any)	Bennis	Bennis	Bennis	Bennis	Bennis hand fired	Bennis hand fired	Bennis hand fired
Heating surface of economiser (if any)	None	None	..	..	None	..	
Heating surface of superheater (if any)	None	None	..	..	..	..	

TABLE No. 5—*continued.*

	1. Derbyshire.	2. Staffordshire.	3. Gloucestershire.	4. Derbyshire.	5. Yorkshire.	6. Durham.	
CONDITIONS OF COMBUSTION (averages)—							
Draught in inches W.G. over fires	..	No observations taken because of other boilers in use	..	..	0·4″	0·4″	0·4″
Draught in inches in main flue	·50″		0·48″	..	..	..	..
Draught in inches at chimney base	1·05″		0·845″	..	..	..	..
Temperature of gases leaving boiler	..		..	..	..	..	..
Temperature of gases leaving economiser	..		..	..	..	..	..
Temperature of boiler room	..		54° Fahr.	..	..	..	..
Percentage of CO2 in gases at downtake	10%		side flue 9·8%	..	..	..	..
Percentage of CO2 in gases leaving boiler	..		..	..	..	..	..
Percentage of CO2 in gases leaving economiser	..		..	..	..	..	..
Smoke produced during test	..		..	..	..	..	..
CONDITIONS OF EVAPORATION (averages)—							
Temperature of feed water entering economiser	..	..	95·2° Fahr.	..	..	..	..
Temperature of feed-water entering boiler	157° Fahr.	50° Fahr.	199·6° Fahr.	263° Fahr.	150° Fahr.	150° Fahr.	167° Fahr.
Steam pressure by gauge	117 lbs.	92·9 lbs.	159·4 lbs.	115 lbs.	138 lbs.	66 lbs.	73 lbs.
Corresponding saturation temperature	..	332·9° Fahr.	370·4° Fahr.	347·20° Fahr.	360° Fahr.	312·70° Fahr.	318·5° Fahr.
Temperature of steam leaving superheater	..	..	501·1° „	..	586° „	..	..
Number of degrees of superheat	..	..	130·7° „	..	226° „	..	..
Heat supplied to each pound of water—							
In economiser	..	..	104·5 B.T.U.	..	..	..	..
In boiler	1065·8 B.T.U.	1165·4 B.T.U.	1031·02 „	958·58 B.T.U.	1075·36 B.T.U.	1064·1 B.T.U.	1048·6 B.T.U.

In superheater	..	..	71·88 B.T.U.	..	124·3 B.T.U.	..	..
Total	1065·8 B.T.U.	1165·4 B.T.U.	1207·4 „	958·58 B.T.U.	1199·66 „	1064·1 B.T.U.	1048·6 B.T.U.
Factor of equivalent evaporation as from and at 212° Fahr. (boiler and economiser and superheater)	..	..	1·2451	..	1·237 No economiser	..	..
Factor of equivalent evaporation as from and at 212° Fahr. (boiler only)	1·0991	1·2067	..	0·9885	..	1·0974	1·0814
NATURE OF COAL USED—							
Name of coal, Class of coal	Hescot Small slack	Holly Bank Colliery dust	Flour Mill Colliery Small	Wingfield Manor Dust	Road sweepings and belt pickings	Gordon house top Coal	Belt pickings
Calorific value per pound as fired	9,938 B.T.U.	7,677 B.T.U.	9,807 B.T.U.	9,649 B.T.U.	8,148 B.T.U.	10,094 B.T.U.	7,676 B.T.U.
Proximate analysis—							
Volatile matter	30·7%	18·1%	22·91%	27·41%	25·38%	36·9%	25·9%
Fixed carbon	47·0%	42·3%	40·9%	47·67%	34·29%	35·8%	35·6%
Ash	22·3%	39·6%	25·69%	14·62%	30·13%	27·3%	38·5%
Moisture	..	..	10·5%	13·00%	12·00%	..	..
QUANTITY OF COAL USED—							
Total weight burned	14,112 lbs.	7,168 lbs.	14,952 lbs.	10,080 lbs.	10,080 lbs.	4,816 lbs.	3,808 lbs.
Weight burned per boiler per hour	1,176 „	1,024 „	1,869 „	1,390 „	1,680 „	1,204 „	1,369 „
Weight burned per sq. ft. of grate per hour	32·7 „	27·0 „	46·7 „	34·8 „	40·0 „	29·4 „	30·9 „
Total weight of ash and clinker	285 „	..	5,396 „	1,390 „	3,094 „	896 „	2,520 „
Percentage of ash and clinker to weight of coal	20·1%	..	35·95%	13·7%	30·7%	18·6%	66·2%
QUANTITY OF WATER EVAPORATED (actual)							
Total quantity of water evaporated	68,100 lbs.	25,450 lbs.	85,100 lbs.	63,200 lbs.	44,900 lbs.	23,200 lbs.	12,850 lbs.
Water evaporated per boiler per hour	5,675 „	3,636 „	10,637 „	8,718 „	7,483 „	5,800 „	4,283 „
Water evaporated per sq. ft. of boiler heating surface per hour	5·68 „	3·64 „	9·812 „	8·04 „	7·48 „	5·81 „	4·29 „
Water evaporated per pound of coal	4·82 „	3·55 „	5·691 „	6·26 „	4·45 „	4·82 „	3·37 „

TABLE No. 5—*continued*

	1. Derbyshire.	2. Staffordshire.	3. Gloucestershire.	4. Derbyshire.	5. Yorkshire.	6. Durham.	
QUANTITY OF WATER EVAPORATED (actual)							
Total heat supplied to water per pound of coal . . .	5143·2 B.T.U.	4137·8 B.T.U.	6871 B.T.U.	6000·71 B.T.U.	5338·49 B.T.U.	5126·1 B.T.U.	3538·5 B.T.U.
EQUIVALENT QUANTITY OF WATER EVAPORATED AS FROM AND AT 212° FAHR.—							
Total equivalent evaporation . . .	74,849 lbs.	30,710 lbs.	105,960 lbs.	62,473 lbs.	55,541 lbs.	25,458 lbs.	13,896 lbs.
Equivalent evaporation per boiler per hour .	6,237 ,,	4,387 ,,	13,245 ,,	8,617 ,,	9,257 ,,	6364·5 ,,	4,632 ,,
Equivalent evaporation per sq. ft. of boiler heating surface per hour . . .	6·24 ,,	4·40 ,,	12·21 ,,	7·95 ,,	9·25 ,,	6·38 ,,	4·64 ,,
Equivalent evaporation per pound of coal .	5·30 ,,	4·28 ,,	7·080 ,,	6·19 ,,	5·50 ,,	5·28 ,,	3·65 ,,
THERMAL EFFICIENCY	51·76%	53·90%	70·07%	62·23%	65·4%	50·78%	46·1%
SUMMARY OF RESULTS—							
Coal burnt per sq. ft. of grate per hour .	32·7 lbs.	27·0 lbs.	46·7 lbs.	34·8 lbs.	40·0 lbs.	29·4 lbs.	30·9 lbs.
Water evaporated as from and at 212° Fahr. per sq. ft. of boiler heating surface per hour . .	5·68 ,,	4·40 ,,	12·21 ,,	7·95 ,,	9·25 ,,	6·38 ,,	4·64 ,,
Water evaporated as from and at 212° Fahr. per pound of coal . . .	5·30 ,,	4·28 ,,	7·08 ,,	6·19 ,,	5·50 ,,	5·28 ,,	3·65 ,,
Thermal efficiency obtained . .	51·76% Boiler only	53·90% Boiler only	70·07% . .	62·23% Boiler only	65·40% Boiler and superheater	50·78% Boiler only	46·1% . .

It is interesting to compare Continental colliery practice with British practice in the utilisation of low grade and waste fuels for the generation of steam.

The author is indebted to Mr A. J. ter Linden and Rijks Instituut Voor Brandstoffen Economie, S'Gravenhage, Holland, for permission to publish the following very complete evaporative tests with very low grade and waste fuels at the Central National Mine, "Emma," Holland. (Table No. 6.)

These figures, it will be observed, are all concerned with water tube boilers, and it is possible to closely compare the results obtained both under hand fired conditions and with mechanical stokers of two distinct types.

Generally speaking the fuels used were so unsatisfactory from the point of view of high moisture content, as also in the high proportion of ash and very low calorific value, as to be fairly regarded as quite unsuitable for steam generation.

If the analyses and calorific values of the fuels used in this series of tests are compared with the poorest of the fuels as per the analyses set forth in Table No. 3, it will be evident that the British interpretation of the term "waste fuels" differs very considerably from the Dutch interpretation.

In the judgment of the Author the series of evaporative tests made by Mr A. J. ter Linden are among the most exhaustive and valuable tests which have ever been made with waste fuels.

The evaporative tests of which details are given in Tables Nos. 5 and 6 have been included with a view to showing the grades of fuel which have been and are being utilised, as also the evaporative performance of boilers of both the internally and externally fired types, both by machine and hand, with the thermal efficiency obtained.

In British practice in the utilisation of the lower grade fuels for steam generation at collieries it was shown many years since that one of the principal difficulties presented was in the very limited grate area which could be provided with internally fired boilers, such as those of the Lancashire type, which were then, and still are, very extensively used at collieries, mainly because of their simplicity and by reason of the considerable advantage offered in the large steam and water reserve for meeting the fluctuating demand for steam.

At some few collieries, with a view to the utilisation of certain waste fuels, unsuitable alike for use with machine or hand fired furnaces, Lancashire boilers were provided with large external brickwork furnaces, designed and arranged on similar lines to refuse destructors. The primary object of these furnaces was to provide externally to the boiler a much larger grate area than could be provided internally, at the same time providing more suitable conditions for the handling and efficient burning of small fuels containing a high percentage of incombustible.

While with a Lancashire boiler 30 ft. long by 8 ft. diameter the usual or standard grate area was about 38 sq. ft., it was possible with external furnaces to increase the grate area to 50, 75 or even 100 sq. ft. if so desired, while also providing 2, 3 or 4 large fire-doors which greatly facilitated both the firing and the clinkering.

TABLE No. 6

Furnace Tests: Central National Mine, "Emma," Holland

Fuel.	Lignite.		Lignite and Washings.		Slack (Mud).		Washings.			
Type of Plant	Pluto stoker	Hand fired	Pluto stoker	Hand fired	Pluto stoker	Hand fired	Chain grate with gas jets	Pluto stoker	Hand fired	
Number of Test	3	4	7	10	13	16	20	28	31	36
Date of Test	22/1/21	24/2/21	8/4/21	24/3/21	16/6/21	26/3/21	2/4/21	13/6/21	30/3/21	10/5/21
Duration of Test Hours	8	12	8	8	8	8	8	8	8	8
PARTICULARS OF BOILERS—										
Boiler heating surface, sq. ft.	3,314	6,456	3,314	6,456	3,314	6,456	3,314	3,314	11,856	11,856
Boiler, grate area ,,	140	117·5	140	117·5	140	117·5	118·4	140	117·5	117·5
Superheater heating surface ,,	807	1,937	807	1,937	807	1,937	807	807	1,937	1,937
Economiser ,, ,, ,,	4,648	..	..	4,648	..	4,648	..	..	4,648	4,648
FUEL ANALYSES—										
Moisture content, per cent.	58	52·5	24	26·7	20·8	30	3·3	7·2	4·7	9·85
Ash, per cent., dry sample	14·8	13·3	29	31·4	22·7	25	37·6	51·7	38·8	65·8
Ash, per cent., wet sample	6·2	6·3	22	23	17·6	17·5	36·3	48	37·	59·3
Percentage combustible (wet sample)	35·8	41·2	54	50·3	61·6	52·5	60·4	44·8	58·3	30·85
Calorific value, B.T.U.'s per lb. (wet sample)	3,168	2,115	3,565	3,265	4,825	4,010	4,680	3,340	4,509	2,180
FUEL CONSUMPTION—										
Total fuel burnt, lbs.	65,340	162,932	41,580	69,454	20,020	54,450	19,470	26,070	55,440	58,080
Burnt per hour ,,	8,250	13,574	5,192	8,668	2,508	6,807	2,433	3,256	6,930	7,260
Burnt per sq. ft. of grate area per hour, lbs.	58	77	37	49	18	38	20·5	23·3	39·15	41

Steam Output—										
Total amount water evaporated . . . . lbs.	113,080	333,960	129,030	215,160	90,156	222,420	118,580	55,000	217,800	39,380
Steam produced by gas jets „	. .	. .	. .	. .	. .	. .	44,220	. .	. .	. .
Steam produced per hour „	14,135	27,830	16,126	26,840	11,264	27,808	14,824	6,875	27,214	4,928
Steam produced per sq. ft. of heating surface per hour, lbs.	4·2	4·3	4·8	5·8	3·4	4·3	4·47	2·08	4·22	·76
Steam produced per sq. ft. of grate area per hour, lbs. .	101	157	116	152	80	157	78·7	49·2	153·7	27·6
Feed Water—										
Temperature entering economiser, °F. . . .	. .	185	. .	163	. .	203	. .	. .	189	167
Temperature, °F. . .	167	325	171	291	176	334	226	199	303	314
Steam—										
Steam pressure, lbs. per sq. in.	176	218	176	213	173	218	179	179	217	204
Steam temperature, °F. .	511	725	502	680	543	680	510	560	702	552
Forced Draught and Chimney Pull—										
Total heat of steam B.T.U.'s per lb.	1,281	1,388	1,276	1,367	1,298	1,365	1,388	1,306	1,377	1,301
Under grate, inches W.G. .	·66	0·78	·74	·55	·39	·39	·75	·71	·63	·51
Over fire, inches W.G. . .	·11	·03	·07	. .	·03	·03	·04 to ·078	·04	·04 to ·078	·04
Draught at chimney, inches W.G.	·55	·39	·35	·55	·19	·55	·35	·20	·51	·60
Combustion—										
Temperature of air supply, °F.	57	77	50	59	85	86	68	82	68	77
Temperature above fire, °F.	2,192	2,219	2,462	2,462	2,552	2,642	1832–2552	2,462	2,624	. .
Temperature of gases leaving boiler, °F.	500	680	572	581	587	599	640	577	620	412
Temperature of gases leaving economiser, °F. . .	. .	437	. .	419	. .	435	. .	. .	422	360
Analysis of Flue Gases—										
CO_2, per cent.	12	13·7	14·5	9·5	12·2	10·5	9·9	9·4	10·8	1·9
CO, „	·3	1·1	·4	·16	·1	·6	·2	·1	·6	. .
O_2, „	6	3·2	1·4	8·7	. .	7·5	7·6	10	7	. .

TABLE No. 6—*continued*

Fuel.	Lignite.		Lignite and Washings.		Slack (Mud).		Washings.			
Type of Plant	Pluto stoker	Hand fired	Pluto stoker	Hand fired	Pluto stoker	Hand fired	Chain grate with gas jets	Pluto stoker	Hand fired	
Number of Test	3	4	7	10	13	16	20	28	31	36
Date of Test	22/1/21	24/2/21	8/4/21	24/3/21	16/6/21	26/3/21	2/4/21	13/6/21	30/3/21	10/5/21
Duration of Test Hours	8	12	8	8	8	8	8	8	8	8
EVAPORATION— Pounds of water evaporated per lb. of fuel burnt	1·73	2·05	3·1	3·1	4·5	4·09	3·82	2·11	3·93	·68
CINDERS— Weight of cinders, lbs.	3,300	6,050	9,504	23,100	3,278	11,880	8,723	12,870	26,180	39,472
Weight of riddlings through grate, lbs.	1,650		880		2,640			4,400		
Weight of dust, lbs.	704	6,336	1,760	1,980	594	3,960	1,716	1,210	1,320	1,408
Ash per cent. in cinders	80·8	89	72·4	73	84	86·7	69	75	71·5	78·9
Ash per cent. in waste	·65	..	58·4	..	25·6	..	..	60·04	..	..
Ash per cent. in dust	78	75	75	79·6	74	60	67	73	67	70·8
ASH BALANCE— Weight of ash in cinders, lbs.	2,662	5,368	6,875	16,830	2,750	10,296	6,017	9,636	18,700	31,196
Weight of ash in riddlings „	1,074	..	515	..	675	..	..	2,651	..	..
Weight of ash in dust „	550	4,752	1,320	1,584	440	2,376	1,100	880	880	990
Total weight of ash „	4,286	10,120	8,710	18,414	3,865	12,672	7,117	13,167	19,580	32,186
Total weight of ash calculated from analysis of fuel, lbs.	4,048	10,252	9,152	15,972	3,520	9,526	7,062	12,540	20,515	34,540
Difference	×238	−132	−442	×2,442	×345	×3,146	×55	×627	−935	−2,354
HEAT BALANCE— Loss in cinders, per cent.	4·5	1·6	14	22·3	4·4	5·9	24	30	23·5	53·3
Loss in riddlings „	4·1	..	1·9	..	16·5	..	..	16·2	..	..
Loss in dust „	1·2	3·7	2·3	1·4	1·3	5·9	4·8	3	1·4	2·6

Sensible heat loss in cinders, per cent.	·6	·3	·9	1·3	·8	·7	1·2	2·4	1·3	3·8
Chimney losses, per cent.	20·8	14·8	13·8	12·5	14·2	13·2	16·8	10·8	9·8	24·6
Loss in unburned gases, per cent.	1·6	4·9	1·6	·8	·5	3·4	1·1	·4	2·8	..
Other losses, radiation, etc., per cent.	3	3	3	3	3	3	3	3	3	3
Total losses, per cent.	35·7	28·3	37·5	41·3	40·7	32·1	50·9	65·8	41·8	87·3
Efficiency ,,	64·3	71·7	62·5	58·7	59·3	67·9	49·1	34·2	58·2	12·7
Calculated per cent. efficiency with flue gases at a temture 392° F. above air temperature	68·2	71·7	66·8	58·7	63·4	67·5	55·6	37·1	58·0	6·3
Efficiency calculated from water evaporated	62·6	66·5	54·9	65	59·8	67·6	49·3	40·2	59·2	20·1
POWER CONSUMPTION OF FURNACE—										
Total power per hour, K.W.	12·5	20	13·5	17	9	15	11·5	13	18	16·5
Power per ton of steam, K.W.	1·95	1·58	1·84	1·37	1·76	1·19	1·71	4·16	1·46	7·4
COST OF FIRING—										
Wages per ton of steam, pence	1·95	5·96	1·72	6·19	2·45	5·96	2·98	4·03	6·11	33·71
Cost of power per ton of steam	1·24	1·00	1·15	·86	1·11	·75	1·07	2·62	·92	4·62
Upkeep	1·30	·27	1·38	·27	2·27	·27	1·59	4·03	·26	1·49
Interest and depreciation per ton of steam for 6000 working hours	1·26	·21	1·11	·21	1·59	·21	2·18	2·61	·21	1·09
Total costs for producing a ton of superheated steam	5·75	7·45	5·37	7·53	8·44	7·20	7·82	13·29	7·50	40·91
Total costs for producing a ton of saturated steam	5·77	6·95	5·46	7·03	8·42	6·95	8·32	13·35	7·07	40·53
Total costs for producing a ton of saturated steam when $T-t=392°$ F.	5·43	6·95	5·12	7·03	7·87	6·99	7·33	12·35	7·10	82·95

A further innovation which was most useful in maintaining a steady steam pressure was the dividing up of the ashpits into separate compartments, each with an independent forced draught supply, enabling one section of the grate to be clinkered while the other sections of the grate were in full use.

Although with the normal grate area of about 38 sq. ft. with a Lancashire boiler it was frequently found impossible to obtain the rated evaporative output from the boiler, by increasing the grate area as already described, and providing forced draught, an evaporation of from 20 per cent. to 30 per cent. in excess of the rated evaporation could be obtained.

While showing a very marked advance in the burning of low grade fuels for steam generation, the external furnace and large grate area was not completely successful, for the following reasons :—

(1) The hand firing of such a large grate, surrounded by incandescent fire-brick walls and arches, was very trying ; the much cooler and easier conditions previously obtaining when using a higher grade fuel were much preferred by the firemen.

(2) The clinkering and cleaning of the fires in spite of the advantage of divided ashpits was extremely arduous work, and as such it was resented.

(3) It was found that the very high furnace temperatures obtained, with the very rapid and localised cooling when the fires were cleaned, involved serious deterioration, due to expansion and contraction. Further, the incandescent fire-brick walls were constantly damaged and weakened. Trouble was also experienced with the arches, and even if these were supported independently of the side walls it was found that the cost of renewal and repair was very heavy.

Had the external furnace fulfilled all expectations, the very limited space available at the front or at the side of the average Lancashire boiler would have prevented its use, excepting in isolated cases.

The external furnace was, however, completely successful in demonstrating that many low grade and very dirty fuels could be efficiently utilised for the generation of steam when ample grate area and suitable combustion conditions were provided.

Further, it was shown that such fuels could be utilised without any sacrifice in the evaporative output of the boiler.

The experience gained in the use of the external furnace clearly showed that it was desirable so far as possible to eliminate the human element and to adopt machine firing.

With internally fired boilers this was not completely successful because of the limited grate area and restricted combustion space : with water tube boilers it was found to be practicable to meet all reasonable requirements.

The only type of boiler which can be equipped with mechanical stokers suitable for efficiently burning low grade fuels is the water tube boiler. With no other type of boiler is it possible to provide the grate area required, equivalent combustion conditions, and at the same time facilities for the easy and automatic removal of incombustible.

These three factors are of vital importance. Unless the grate area is ample the required evaporative output cannot be obtained. Unless the combustion conditions are satisfactory the fuel efficiency obtained is low, which involves a constant loss. Unless facilities can be provided for the rapid and easy removal of incombustible, with but the minimum of labour cost, it is soon found that the use of so-called cheap low grade fuels is in practice a very expensive method of generating steam.

It is useless to ignore the fact that the three requirements mentioned above are not fully met in the Lancashire boiler, whether hand fired or machine fired. The grate area is limited, the combustion space is restricted, and the removal of the incombustible—which must in any case be brought to the front—involves the use of manual labour, the extent and cost of which depends entirely upon the percentage of incombustible, and the means employed for its removal from the front of the boiler.

While the Lancashire boiler is specifically referred to, it may be said that the objections named apply equally to all internally fired boilers. Actually boilers of the fire tube type, such as dry-back boilers, are less satisfactory than those of the Lancashire type, because, apart from the objections already discussed, the utilisation of low grade and dirty fuel involves the rapid choking of the tubes, necessitating constant cleaning, or, alternatively, back draught and consequent inefficiency is certain.

It may be unfortunate, but the fact remains that for the most efficient utilisation of low grade fuel one type of boiler is superior to all other types. The author is well aware that this is a contentious matter, but would submit that on the broad facts, and by experience, it is clearly and conclusively shown, that internally fired boilers are incapable of giving results in any way equivalent to, or comparable with, those results obtainable with externally fired or water tube boilers.

While, as observed in the preface, the use of coal in pulverised form does not come within the scope of this work, there can be no doubt that this system of firing will be extensively employed at collieries within the next few years, both with internally and externally fired boilers, enabling fuels to be efficiently utilised which are now to a serious extent regarded as unuseable.

CHAPTER III

LIGNITE AND BROWN COAL

ALTHOUGH it is sometimes assumed that lignite and brown coal are almost identical, it is frequently found that there are very marked and distinct differences in these fuels, not only in their appearance, but in their physical characteristics and composition.

In lignite almost invariably the form and structure of wood is very evident, often with but little change in appearance from the original. Other lignites are of a more fibrous character with much variety, some being very dense, while others are of a loose and earthy nature.

Brown coal usually is a dense fuel resembling a hard peat, and is as a general rule free from the woody structure, which is such a marked feature of many lignites. Close examination of brown coal does, however, sometimes show traces of a similar structure.

While differing in their appearance, physical characteristics and composition, all lignites and brown coal possess certain characteristics in common. The moisture content although varying, is high, while upon exposure to the atmosphere disintegration is frequently rapid with consequent deterioration. The ash content varies considerably, as also its composition.

As observed in a preceding chapter, the efficient utilisation of these fuels is of much importance because of their proportion to the total available coal reserves, not only within the British Empire, but in other countries.

According to statistics issued by the United States Geological Survey in April 1921, the production of lignite during 1920 was as follows :—

	Metric Tons.
Austria	2,387,996
Czecho Slovak Republic	19,695,600
France	1,000,000
Germany	11,634,000
Italy	1,662,430
Netherlands	1,395,851
Spain	552,866

Great Britain.—In Great Britain the only known lignite deposit of any importance is at Ilsington, Bovey Tracey, Devonshire, on the south-eastern fringe of Dartmoor. In 1853 the output was about 18,000 tons, and until coal was available locally at a low price, the lignite was used, not only for domestic purposes, but also at a neighbouring pottery.

During recent years schemes have been under consideration for the development and local use of this deposit, but up to the present nothing appears to have been

done. Four samples of Bovey Tracey lignite analysed a few years since gave the following results :—

No. of Sample.	Fixed Carbon.	Volatile matter.	Ash.	Moisture.	Calorific value B.T.U.'s.
(1)	38·54	48·57	·79	12·10	11,040
(2)	25·68	20·60	17·27	27·45	5,276
(3)	29·65	35·88	3·02	31·45	6,948
(4)	26·11	26·53	8·36	39·00	5,695

It will be observed that the results shown in the approximate analysis of sample No. 1 are altogether different from the test results obtained with the other three samples. In explanation of this it may be said that the latter probably represents approximately the composition of the bulk of the deposit, while of the former, which is known locally as " Rectinite," comparatively small quantities are found.

The " Rectinite " appears to contain a large percentage of aromatic resinous material, and may be readily ignited with a match. The true lignite contains an unusually high percentage of sulphur.

Germany.—The development of the lignite resources of Germany has within recent years become of much greater importance to the nation by reason of the reduced output of coal due to decreased efficiency of the miners, and to the loss of important coal-fields in Upper Silesia and the Saar Valley.

In the interests of brown coal development a chair of Brown Coal Technology has been created at Freiburg Mining School, while at the Technical University of Charlottenburg a Brown Coal Technological and Research Department has been established by the brown coal industry.

In 1872 the production of lignite in Germany was only 9 million tons ; thirty years later it had increased to over 40 million tons per annum. During the next decade the output reached 70 million tons per annum.

The following Table, No. 7,[1] shows the comparative annual production of lignite, lignite briquettes, coal, and coke for the years 1913 to 1921 inclusive :—

TABLE No. 7

Production in Germany of Lignite and Lignite Briquettes as compared with Coal and Coke

Year.	Bituminous Coal.		Lignite.		Coke.		Lignite Briquettes.	
	Tons.	%	Tons.	%	Tons.	%	Tons.	%
1913	173,096,000	100·	87,233,000	100·	30,400,000	100·	21,416,000	100·
1914	148,504,000	85·8	83,694,000	95·9	27,137,000	89·3	21,098,000	98·5
1915	136,502,000	78·9	87,948,000	100·8	26,209,000	86·2	22,750,000	106·2
1916	147,916,000	85·5	94,332,000	108·1	33,139,000	109·0	23,484,000	109·6
1917	154,845,000	89·5	95,543,000	109·5	32,434,000	106·7	22,048,000	102·9
1918	148,187,000	85·6	100,675,000	115·4	32,309,000	106·3	23,111,000	107·9
1919	107,691,000	62·2	93,843,000	107·6	21,206,000	59·8	19,716,000	92·1
1920	131,347,000	75·9	111,634,000	128·0	25,177,000	82·8	24,282,000	113·4
1921	136,210,000	78·7	123,011,000	140·9	27,921,000	91·6	28,243,000	131·9

[1] " Reich Kohlen Verband," 2nd Annual Report, year ended March 30th, 1922.

It will be observed that during the past ten years the production of bituminous coal has decreased to the extent of 36,886,000 tons per annum, while during the same period the production of lignite has increased to the extent of 35,778,000 tons per annum.

The character of the lignite and brown coal deposits in Germany varies considerably. Faults, folds, thrust faults, ruptures, and interstratified layers of sand and shale often make the mining of the deposit very difficult.

The thickness of the bed varies from a few inches to 300 feet. The method of mining adopted, whether by strip pit, *i.e.* open cut, or by underground mining, depends upon the depth and extent of the overburden, which usually consists of sand and clay.

When underground mining is adopted the coal is usually reached by means of a shaft rather than by a drift, an entry being driven through the deposit to the further property line, with side entries on either side at regular intervals, with cross roadways between. Thus the coal is divided up into pillars measuring 4 metres (13 feet) square; the coal obtained from these pillars is transported through the side entries to the main entry, and thence up through the shaft.

Fig. 1.—Mining Brown Coal by Hand (Germany).

The roof of the area thus excavated is allowed to collapse. Production is started at the far end of the field and proceeds backwards towards the shaft.

Much lignite has to be left in, and it has been reported that in mines operated under this system the loss of fuel usually exceeds 40 per cent., whereas under the open cut system of mining the loss is usually about 5 per cent., and rarely reaches 10 per cent.

The loss of fuel in underground mining appears to be so heavy that, even if the thickness of the overburden is three times that of the underlying coal deposit, it is nevertheless more profitable to remove this heavy proportion of waste material by open cut operation rather than working by underground methods.

By the adoption of mechanical excavators or dredges, the overburden is rapidly stripped and removed. These machines, which are set on rails, slowly traverse the face, removing the material and loading into self-tipping wagons in one operation. For the mechanical winning of the coal, with a view to reducing the cost of mining, various machines have been tried. One very successful type of traversing cutter and excavator is constructed to operate on any height of coal face up to 100 feet,

consisting of a body travelling on rails supporting a framework carrying two link belts with cutters, the loading buckets being suspended underneath. These machines, which are electrically operated and controlled, cut and load, with a crew of two only—one mechanic and an assistant.

When the fuel is mined by hand, as illustrated in Fig. 1, it is directed into cars by means of chutes laid close up to the coal face, or holes are dug into the coal face as shown in Fig. 2.

This method is known as *rollochbetrieb.* The narrow end of the "rolloch" is closed by means of timber, and is arranged at such a height above the level of the top of the cars to be loaded that these can be run underneath and filled by gravity, the loose coal in the funnel being released as desired. Usually the sides of the "rolloch" are arranged so steep that the loosened lignite will run down without any handling.

Fig. 2.—Mining Brown Coal by Hand (Germany).

The cars are generally conveyed from the mine to the briquetting plant by endless chain haulage. When the raw lignite reaches this plant it is subjected to three entirely distinct operations, viz., preparation, drying, and briquetting.

The fuel is first discharged from the car by means of a rotary tippler and delivered into a funnel-shaped bunker, from which it goes forward to the crushers. From the crushers the broken fuel is delivered on to an inclined shaking screen, which has a length of from 13 to 20 feet and a width of about 4 feet.

From this screen pieces less than $\frac{1}{2}$-inch. cube riddle through, the larger pieces passing forward to the rollers or to a centrifugal mill. The finer coal is again screened, the lumps from the screen passing to a belt conveyor, by means of which it is transported to the boiler-house. The wet fuel intended for briquetting is dried either in tubular or shelf dryers: with both types of dryer exhaust steam is used for drying; this process is usually continued until the water content is reduced to 15 per cent.

With dryers of the tubular type the pressure of steam used is generally from 2 to 3 atmospheres absolute. For dryers of the shelf or plate type the steam pressure ranges from 1·5 to 2 atmospheres.

The tubular dryer may be described as a cylindrical sheet-iron shell 8 ft. $2\frac{1}{2}$ ins. to 9 ft. 10 ins. long, with two heavy plate ends carrying tubes of $3\frac{1}{2}$ ins. diameter

through which the coal passes. These tubes are surrounded by exhaust steam. The centre line of the dryer is arranged at an angle of 6 degrees from the horizontal.

The shelf or plate dryer (*tellertrockner*) consists of from 25 to 36 circular shelves, each having a diameter of 16 ft. $4\frac{3}{4}$ ins. arranged veritically above each other at regular intervals. The shelves are made up of two circular iron sheets riveted to a frame, the space between the sheets providing a chamber for the exhaust steam.

By means of rotary shovels the lignite is constantly turned over and pushed alternately towards openings at the centre and outer circumference which connect the separate shelves.

From the dryer the dry coal is delivered on to a trommel or revolving screen and is there separated into fine coal and coal dust, passing thence into a *Jalousie-*

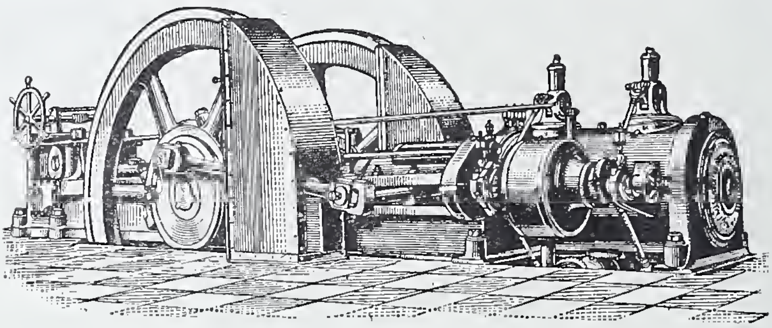


FIG. 3.—STEAM BRIQUETTING PRESS ENGINE, FOR GERMAN BROWN COAL.

kuehler or air cooler of the lattice type, in which the temperature of the fuel is suitably reduced for the process of briquetting.

Leaving the cooler the dried and cool lignite is taken by means of a conveyor to the bunkers, which are arranged immediately above the briquetting presses.

Steam-driven presses of the plunger type are now almost exclusively used for the briquetting of lignite and brown coal. The use of steam-driven plant is favoured mainly because exhaust steam is required for the operation of the dryers. With the presses usually employed the stroke varies from $6\frac{1}{4}$ ins. to almost 11 ins., depending upon the condition of the fuel and the desired density of the briquette. A rod transfers the crank movement to a heavy slide, to the other end of which a plunger is attached. The principal part of the press is the head, in which is placed the mould, consisting of a channel 3 ft. 3 ins. long, open at both ends. The sides of the mould are of interchangeable steel plates so set that the free opening is of the desired dimensions for the size of briquette which is being made. The plates are so formed that the opening on the press side is a few millimetres wider than the rest of the channel.

The difference in width depends upon the nature of the fuel used and the desired firmness or density of the briquette. The opening can be regulated while the press is in operation. The plunger, fitting closely in the widest end of the channel, pushes a quantity of dry coal into the mould and forms a briquette with every forward movement.

On the return stroke the space left by the plunger is again filled with another measured quantity of fuel, which is compressed at the next stroke. Each briquette is pushed forward in the mould by the succeeding charge. On passing the narrowest part the briquette is again subjected to pressure, causing friction and consequently back pressure on the plunger.

Leaving the passage way or channel the briquettes pass into a trough, through which they are pushed in a continuous string by the action of the plunger. This trough may be adjusted either horizontally or vertically, and the briquettes may be discharged therefrom direct into railway wagons.

Not only the length of the stroke, but also the speed of the press, depend greatly upon the condition of the coal. The speed is usually from 80 to 125 r.p.m. The pressure required for the formation of the briquette is from 1200 to 2000 atmospheres (17,640 to 29,000 lbs.) per square inch. The press must be so built that the fly wheels are capable of exerting such pressures.

Fig. No. 3 illustrates a Steam Briquette Press. The press and engine are arranged upon a common bedplate, and a single crankshaft serves for both parts of the unit.

In Fig. No. 4 is shown a complete plant for crushing, sizing, re-crushing, re-sizing, drying, cooling, and briquetting brown coal.

The dry coal is held together without any added binder, partly as the result of the high pressure exerted upon it, and partly through the heat generated in the process, which softens the coal and the substances contained, such as paraffins and resins.

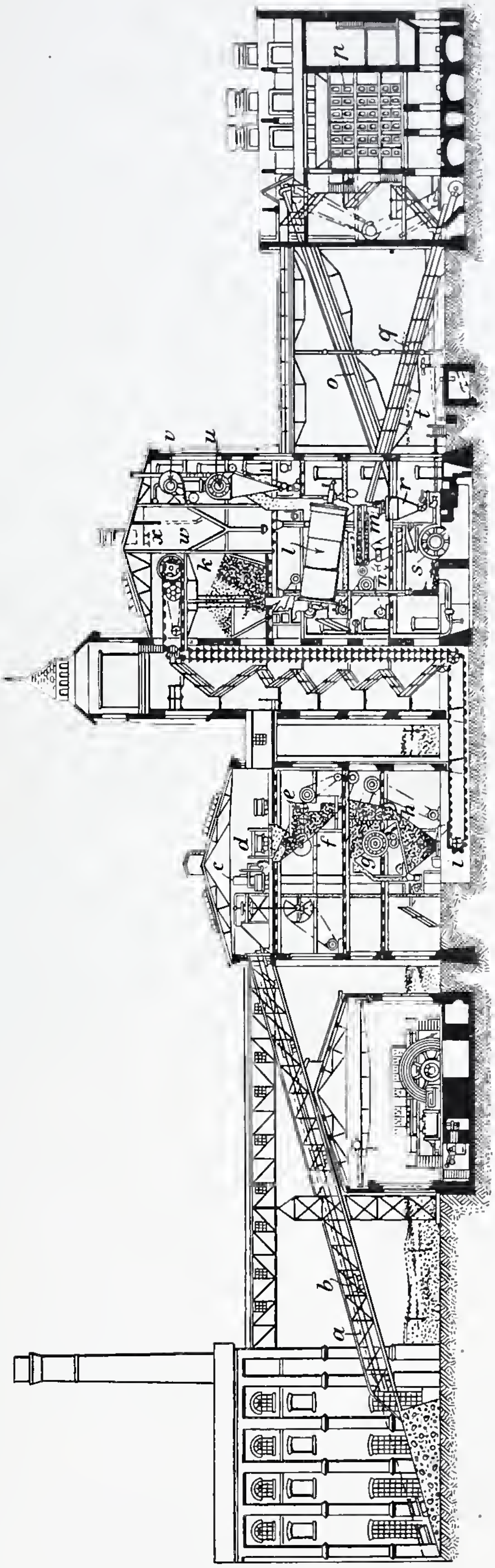


Fig. 4.—Complete Plant for Crushing, Re-crushing, Re-sizing, Drying, Cooling and Briquetting Brown Coal (Germany).

The calorific value of lignite briquettes is about 8500 B.T.U.'s per pound, and they are now used for a variety of purposes. As will be observed from Tables Nos. 7 and 8 the annual production now exceeds 28 million tons.

It is generally agreed that 9 tons of raw lignite (*Rohbraunkol*) are equal to 2 tons of bituminous coal (*Steinkol*), and that 7 tons of lignite briquettes (*Braunkohlenbricketts*) are equal to 4 tons of bituminous coal.

Lignite is now being used in some very large generating stations in Germany for steam generation, and there is no doubt that, as a cheap and inexpensively mined fuel. it is destined to play a very important part in electrical development upon a very large scale, which will be of great advantage in providing cheap power for many industries.

While it must not be assumed that German engineers possess a monopoly in their experience of lignite, yet it must be admitted that in the development of the deposits of this fuel, and in the constant expansion of an important briquetting industry, they have acquired a very valuable experience in the treatment of this high moisture fuel.

The experience of German makers of briquetting plant, as also the fact that they are able to manufacture lignite briquettes without the use of any binding medium, was undoubtedly mainly responsible for the decision of the Electricity Commissioners of Victoria, Australia, to instal German briquetting plant in connection with the important Morwell project, which will be referred to later.

The following Table, No 8,[1] shows the comparative consumption of bituminous coal, coke, brown coal, and brown coal briquettes in Germany in 1921, as also the use to which the brown coal and brown coal briquettes was put :—

TABLE No. 8

	Bituminous Coal.	Coke.	Brown Coal.	Brown Coal Briquettes.
	Tons.	Tons.	Tons.	Tons.
	64,704,000	21,466,000	39,376,000	26,339,000
Railways	13,483,000	2,934,000	88,000	202,000
Shipping	2,628,000	5,000	..	20,000
Water Works	467,000	15,000	..	..
Gas Works	6,793,000	70,000	..	..
Electricity Works	4,478,000	44,000	9,739,000	1,076,000
Domestic Agriculture, etc.	7,192,000	3,315,000	1,555,000	14,481,000
Industry	29,361,000	14,978,000	23,344,000	10,135,000

Canada.—Although about one-sixth of the coal resources of the world are possessed by the Dominion of Canada, the deposits are confined to the eastern and western portions of the Dominion, the central portion being supplied with imported coal.

[1] "Reich Kohlen Verband." 2nd Annual Report, year ended March 30th, 1922.

Hence it is that with no fuel other than peat and timber available in the very extensive region between the Atlantic bituminous coal areas and the lignite deposits of Saskatchewan, the provinces of Quebec, Ontario, and Manitoba have been supplied mainly by means of imported coal from the United States, supplemented by supplies from Eastern and Western Canada.

Mr R. A. Ross in his Report [1] to the Honorary Advisory Council for Scientific and Industrial Research on "The Briquetting of Lignite," thus referred to the position :—

"As more than half of the coal used in Canada is imported from the United States, and as nearly all is used in this naturally coalless region, our dependence upon the United States constitutes at once an industrial menace and a national problem.

"Fortunately this problem is capable of solution. Superabundant unutilised water powers can provide ample energy for industrial requirements in Eastern and Central Canada. Further west the feasibility of meeting requirements in Saskatchewan and Manitoba by utilising prepared lignites and sub-bituminous coals is the subject of this report."

The actual and probable reserves of lignite, and lignitic or sub-bituminous coals in Western Canada is as follows :—

Actual Reserves

	Lignite.	Lignitic or Sub-Bituminous.
	Millions Metric Tons.	Millions Metric Tons.
Saskatchewan	2,412	..
Alberta	..	382,500
British Columbia	..	60
	2,412	382,560

Probable Reserves

	Lignite.	Lignitic or Sub-Bituminous.
	Millions Metric Tons.	Millions Metric Tons.
Manitoba	160	..
Saskatchewan	57,400	..
Alberta	26,450	464,821
British Columbia . . .	..	5,136
	84,010	469,957

[1] "Report No. 1 to the Honorary Advisory Council for Scientific and Industrial Research." Canada, 1918. By Mr R. A. Ross.

Fully realising the great potential value of the very considerable deposits of lignite, as also the necessity for such development as will enable the importation of coal to be much reduced, the Canadian Government have for some years past devoted close attention to the problems involved.

Both the Canadian Government Department of Mines at Ottawa and the Commission of Conservation have done a great deal of very valuable work, which must be of immense advantage in furthering the development of the enormous fuel and power resources of the Dominion, and in overcoming the difficulties which exist.

When the author was in Canada in the autumn of 1920 he was privileged to see something of the work which had been and was being done, and the opinion then formed was that fuel conservation problems were being tackled with a thoroughness which might with advantage be emulated in Great Britain, and also in other British dominions.

With a view to the utilisation of lignite both for industrial and domestic purposes, and particularly for the latter [1] much valuable experimental work has been done. Not only has a complete investigation been made of all Canadian fuels, covering both proximate and ultimate analyses, but the work done has also comprised Producer Tests in the production of power or fuel gas, research and experimental work in the carbonisation and briquetting of lignites, and practical steam boiler trials with a considerable range of lignites.

In the manufacture of carbonised lignite briquettes the raw lignite is heated in closed retorts somewhat similar to bye-product coke ovens.

The volatile matter and moisture is driven off in the form of a gas, a portion of which may be used for heating the retort, and the remainder recovered.

The carbonised material, unlike bituminous coke, is hard and dense, consisting chiefly of slack or breeze. When briquetted it produces a fuel similar in many respects to anthracite.

Raw lignite, as used for firing steam boilers at the generating station of the city of Edmonton, Alberta, was reported to have the following composition :—

Fixed carbon	29·00	per cent.
Volatile matter	28·00	,,
Moisture	25·00	,,
Ash	18·00	,,
Calorific power (B.T.U.'s), as fired .	7800	

Analyses of a number of samples of Alberta and Saskatchewan and typical Canadian lignites are given in the following Tables, Nos. 9 and 10 :—

[1] In 1918 the Lignite Utilisation Board was established with a view to the complete investigation of all apparatus and processes for carbonisation and briquetting. Further, to provide a plant of commercial size adjacent to developed mines in Southern Saskatchewan, the immediate objective being the production of domestic fuel.

TABLE No. 9

Chemical Analyses of Alberta and Saskatchewan Lignites [1]

	Tofield.	Gainford.	Rosedale.	Cardiff.	Twin City.	Souris.
Moisture	25·0	17·0	16·5	20·0	18·1	29·7
Fixed carbon	36·7	43·8	43·4	40·4	41·3	49·6
Volatile matter.	29·8	30·8	33·6	31·6	33·3	44·5
Nitrogen	0·9	1·6	1·3	1·2	1·1	1·3
Sulphur	0·3	0·6	0·4	0·2	..	0·6
Ash	8·5	8·4	0·5	8·0	7·3	12·4
Calorific power (B.T.U.'s). .	7,990	9,040	9,650	8,787	9,685	10,170 [2]

TABLE No. 10

Proximate Analyses of Typical Canadian Lignites.

Locality.	Moisture freshly mined %.	Proximate Analyses, Dry. Volatile matter.	Fixed Carbon.	Ash.	B.T.U.'s.
Taylorton	28·6	42·9	49·0	8·1	..
Estevan	30·9	40·0	43·2	16·8	..
Bienfait Mine	29·25	29·05	35·90	5·90	7605
Estevan Coal and Brick Co. Upper porton 3 ft. 6 ins. .	25·67	28·94	38·59	6·80	8073
Lower portion 3 ft. . . .	26·20	26·70	35·95	11·15	..
Willow Bunch Lake . .	20·15	28·47	34·18	17·20	6388
Bienfait Lower Seam . .	22·40	29·73	37·97	9·90	..

Lignite, as mined, has been satisfactorily used in Western Canada for the firing of steam boilers for some years past. In 1913–14 steam boiler tests with Alberta

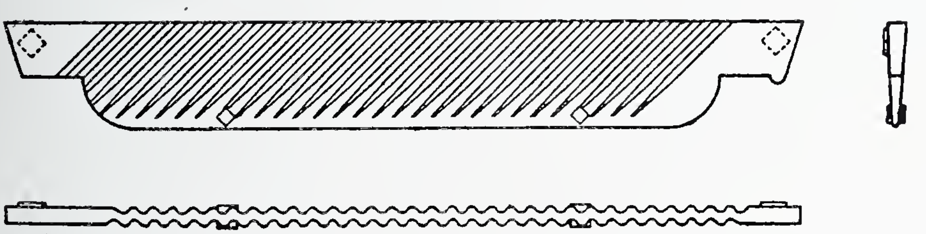


FIG. 5.—TYPE OF FIREBAR USED IN EVAPORATIVE TESTS WITH ALBERTA LIGNITES AT OTTAWA.

lignites were conducted at the Fuel Testing Station of the Canadian Government, Department of Mines, by Mr B. F. Haanel, B.Sc., Chief of the Fuels and Fuel Testing

[1] "Peat Lignite and Coal," by B. F. Haanel, B.Sc., Chief of Fuels and Fuel Testing Division, Canada, Department of Mines, 1914.

[2] Dry coal.

Division, and Mr John Blizard, B.Sc. The following details of these tests are of interest, particularly having in mind that the boiler used was not provided with any special equipment, nor was the grate or furnace in any way altered from that usually employed for the burning of coal.

The boiler used for the tests was of the Babcock & Wilcox Marine type, having 677 sq. ft. of heating surface. The working steam pressure was 120 lbs. per sq. in., the grate area 23·2 sq. ft., the ratio of heating surface to grate area being 29. The grate used was of corrugated firebars having an air spacing of approximately ¼ in.; the type of firebar used is illustrated in Fig. 5.

TABLE No. 11

Steam Boiler Tests with Alberta Lignites at the Fuel Testing Station of the Department of Mines, Ottawa

Fuel.	Rosedale.	Cardiff.	Twin City.	Canmore.	Pembina.	
Duration of tests	12	12	12	12	12	hours.
Proximate analysis of fuel as fired—						
Moisture	15·3	21·2	15·9	2·9	17·0	per cent.
Fixed carbon	45·0	39·1	40·8	71·7	43·8	,,
Volatile matter	32·1	32·1	29·8	13·1	29·5	,,
Ash	7·6	7·6	13·5	12·3	9·7	,,
Calorific value of fuel as fired per lb.	9600	8570	8530	12920	8980	B.T.U.
Hourly quantities—						
Fuel as fired per hour	470	473	465	295	434	lbs.
Fuel as fired per sq. ft. of grate per hour	20·2	20·3	20·0	12·7	18·6	,,
Equivalent evaporation from and at 212 deg. Fahr. per hour	2554	2404	2427	2377	2456	,,
Equivalent evaporation from and at 212 deg. Fahr. per sq. ft. of heating surface	3·77	3·55	3·59	3·51	3·63	,,
Average temperatures, pressures, etc.—						
Steam pressure per sq. inch	108	108	107	105	109	,,
Feed water	38·5	35·5	35	37	37·5	Fahr.
Moisture percentages in steam	0·9	0·8	0·8	0·8	1	per cent.
Pressure difference of draught above and below grate	0·21	0·20	0·21	0·32	0·21	inches.
Pressure difference of draught between gas exit and ashpit	0·57	0·46	0·63	0·68	0·63	,,
Average temperatures, pressures, etc.—						
Gas temperature at boiler exit	730	670	690	630	645	Fahr.
Flue Gas—						
Average carbon dioxide in dry flue gases by volume	8·5	10·2	9·0	7·5	7·7	per cent.
Average carbon monoxide in dry flue gases by volume	0·4	0·7	0·2	0·05	0·4	,,
Lbs. of dry flue gas per lb. of carbon	28·0	22·9	27·1	32·8	30·6	lbs.
Heat loss due to escaping dry flue gas	25·5	18·9	32·7	24·0	24·7	per cent.
Heat loss due to moisture escaping with flue gas	6·9	8·2	7·3	3·6	7·4	,,

TABLE No. 11—*continued*

Fuels.	Rosedale.	Cardiff.	Twin City.	Canmore.	Pembina.	
Refuse removed from grate and ashpit—						
Total refuse removed, percentage of fuel as fired	7·8	8·5	9·2	15·0	9·6	per cent.
Combustible in refuse removed	14·8	14·9	18·9	27·7	16·1	,,
Combustible in refuse, percentage of combustible in fuel as fired	1·5	1·8	2·5	4·9	2·1	,,
Economic Results—						
Equivalent water evaporated from and at 212 deg. Fahr. per lb. of fuel as fired	5·43	5·08	5·22	8·05	5·67	lbs.
Equivalent water evaporated from and at 212 deg. Fahr. per lb. of dry fuel	6·41	6·45	6·21	8·29	6·83	,,
Equivalent water evaporated from and at 212 deg. Fahr. per lb. of combustible consumed	7·17	7·28	7·73	10·03	7·94	,,
Fuel Efficiency—						
Heat utilised in steam raising, per cent. of total heat energy in fuel fired	54·9	59·5	59·4	60·4	61·2	per cent.
Heat utilised in steam raising, per cent. of total heat energy in combustible consumed	55·9	58·6	62·2	63·9	62·8	,,
Calorific values of fuel used in tests—						
Gross calorific value, B.T.U. per lb. as fired	9600	8570	8530	12920	8980	B.T.U.'s.
Net calorific value, B.T.U. per lb. as fired	9070	7990	8020	12520	8440	,,
Boiler and furnace efficiency based upon gross calorific value per cent.	54·9	57·5	59·4	60·4	61·2	per cent.
Boiler and furnace efficiency based upon net calorific value per cent.	58·1	61·7	63·2	62·3	65·1	,,

The conclusions arrived at as the result of these trials with lignites were (1) that the moisture content [1] of the fuels up to 30 per cent. does not materially affect the boiler efficiency ; (2) that the carbon hydrogen ratio exercises the greater influence in this direction ; (3) that the lower rate of consumption per sq. ft. of grate surface with the more suitable type of firebar in these trials improved the efficiency shown ; (4) that fuels of this class require a specially large combustion chamber, and brick ignition arch so arranged as to burn the large percentage of volatile matter contained.

Such experimental work as has already been done in Canada in the carbonisation and briquetting of lignite has clearly shown that, given an efficient and economical system of carbonisation, there is every promise of producing a domestic fuel which is likely to be in every respect quite satisfactory.

Fig. 6 is a " Flow Sheet " illustrating the proposed general lay-out of a carbonising and briquetting plant as projected by the Lignite Utilisation Board of Canada.

[1] The drop in efficiency, when burning lignites having more than 30 per cent. of moisture content, suggests the importance of preliminary drying, or the use of pre-heated air for combustion, or both.

A combined carbonising and briquetting plant of sufficient capacity to test the whole process upon a commercial and practical scale has been erected at Bienfait, Saskatchewan. It is anticipated when this plant has been thoroughly tested and the commercial possibilities have been demonstrated, that the Canadian Government will then leave the future development of lignite to private enterprise.

In a paper read by Mr Leslie R. Thomson, Secretary of the Lignite Utilisation Board of Canada, before the Montreal Branch of the Society of Chemical Industry, the position was thus summarised :—

"(1) It is possible to make a first quality commercial fuel briquette from carbonised lignite, using any one of such binders as coal-tar pitch, petroleum pitch, hard-wood tar pitch, sulphite liquor pitch, or combinations of them.

"(2) The quantity of binder required is much in excess of that necessary to make a correspondingly good briquette from anthracite fines.

"(3) A waterproof briquette of carbonised lignite cannot be made using sulphite

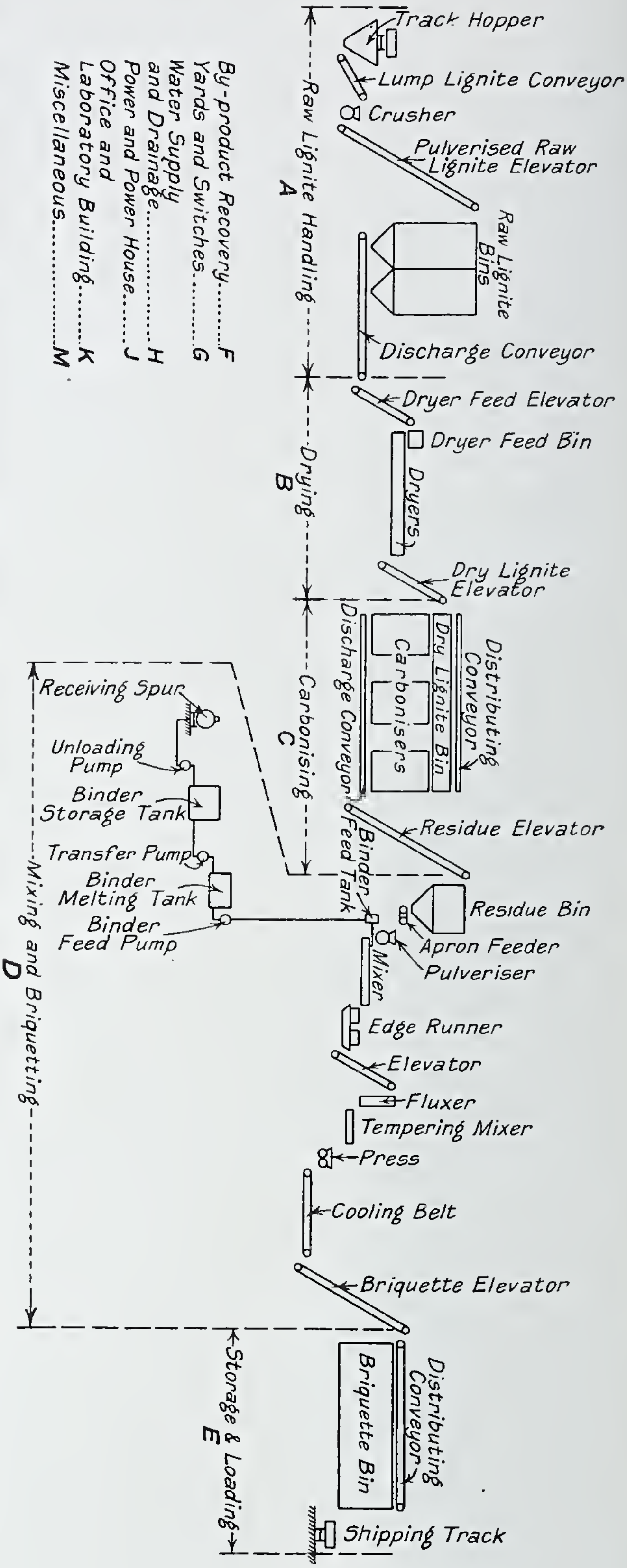


Fig. 6.—"Flow Sheet," showing proposed lay-out of a Carbonising and Briquetting Plant, by the Lignite Utilisation Board of Canada.

pitch as a single binder, unless the briquettes are heat-treated subsequently.

"(4) The choice of binder does not rest so much with the technical difficulties involved in its use, but with the economic supply of that particular binder. In other words, the Lignite Board has succeeded in making good briquettes with many binders.

"(5) The Board has decided to use as a binder coal-tar pitch for the preliminary period of operation, in the proportion of 13 parts by weight to every 100 parts of carbonised lignite."

The proposed price of carbonised lignite briquettes at Winnipeg (the limit of Eastern distribution) was \$17·50 per short ton (2000 lbs.), as against \$20 for

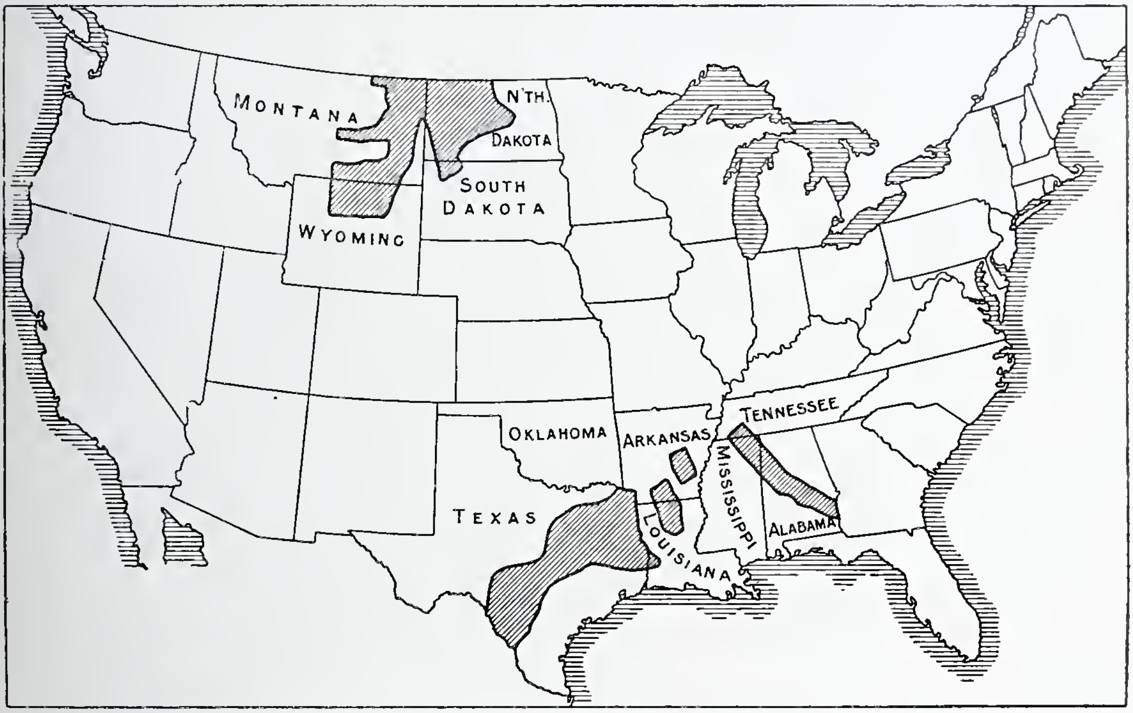


FIG. 7.—PRINCIPAL LIGNITE-BEARING REGIONS IN THE UNITED STATES.

United States anthracite. The briquettes have a calorific value of 10/11ths of that of United States anthracite, in addition to which it was claimed that they possessed better burning qualities, and that they do not clinker.

Carbonisation at about 600° C. yielded a residue having the highest B.T.U. content.

The following analysis gives the composition of a straight coal-tar pitch briquette :—

Fixed carbon	=	59·8 per cent.
Volatile matter	=	19.4 ,,
Moisture	=	4·3 ,,
Ash	=	16·5 ,,
		100·00 ,,
B.T.U.'s	=	11,280

The production of lignite in Canada in 1921 reached 3,217,000 tons, while the importation of United States coal to Central Canada was 18,102,620 short tons.

United States.—The principal regions in the United States in which lignite is found are shown in Fig. 7. The total resources of lignite, brown coal, and sub-bituminous coal are given as 1,863,542 million tons, or nearly one-third of the total coal resources. The estimated tonnage of lignite is given as 1,051,290 million tons.

The principal deposits are in North and South Dakota, and Montana, with smaller deposits in Texas, Alaska, and in Western and Southern States.

The moisture content generally appears to vary from 20 per cent. to 40 per cent., and while the opinion has been prevalent that these high moisture fuels cannot be efficiently utilised for the generation of steam, a considerable quantity is now being used for this purpose, although there is no doubt that the average thermal efficiency obtained will be low.

The following Table, No. 12, gives proximate and ultimate analyses of Texas, North Dakota, Arkansas and Alaska lignites :—

TABLE No. 12

Texas Lignites

	Proximate Analyses.				Ultimate Analyses.					
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	B.T.U.'s.
Wooter's Mine, Houston County	34·70	33·23	21·87	11·20	·79	6·93	39·25	·72	41·11	7056
Olsen Mine, Milain County	31·06	27·67	33·89	7·88	·99	6·53	44·70	·90	39·00	7870
Hoyt Mine, Wood County	33·71	29·25	29·76	7·28	·53	6·79	42·52	·79	42·09	7348

North Dakota and Arkansas Lignites

	Proximate Analyses.				Ultimate Analyses.					
	Moisture.	Volatile content.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	B.T.U.
North Dakota										
Wilton . .	35·96	31·92	24·37	7·75	1·15	6·54	41·43	1·21	41·92	7069
Lehigh . .	32·64	29·19	26·75	11·42	3·54	6·15	39·53	·49	38·87	6970
Williston . .	38·92	25·54	30·15	5·39	·48	6·89	39·34	·68	47·22	6739
Arkansas										
Lester Mine (Ovachita) .	39·43	26·49	24·37	9·71	·49	6·98	36·33	·68	45·81	6356

TABLE No. 12—*continued*

Alaska Lignites [1]

	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.
Port Graham, 1 sample	16·87	37·48	39·12	6·53	·39
South-Eastern Alaska, average 5 samples	1·97	37·84	35·18	24·23	·57
Wainwright Inlet, 1 sample	10·65	42·99	42·94	3·42	·62
Colville River, 1 sample	11·50	30·33	30·27	27·90	·50
Upper Yukon (Canadian), average 13 analyses	13·08	39·88	39·28	7·72	1·26
Upper Yukon (Circle Province), average 3 analyses	10·45	41·81	40·49	7·27	1·30
Upper Yukon (Rampart), average 6 analyses	11·42	41·15	36·95	10·48	·33
Seward Peninsula, 1 sample	24·92	38·15	33·58	3·35	·68
Chitistone River, 1 sample	1·65	51·50	40·75	6·10	..
Kachemak Bay, average 6 analyses	19·85	40·48	30·99	8·68	·35
Nenana River, 1 sample	13·02	48·81	32·40	5·77	·16
Kodiak Island, 1 sample	12·31	51·48	33·80	2·41	·17
Unga Island, average 2 analyses	10·92	53·36	28·25	7·47	1·36
Tyonek, average 4 analyses	8·35	54·20	30·92	6·53	·38
Chistochina River, 1 sample	15·91	60·35	19·46	4·28	..

In spite of the fact that lignite is only used to a very limited extent in the United States, and in districts very remote from the ordinary coal-fields, much experimental work has been carried out, not only in the burning of raw lignite for steam generation, but also in carbonisation and briquetting.

Generally it may be observed that carbonisation is favoured, as a means of providing not only a much more valuable fuel, but also in recovering valuable by-products. It is, however, becoming increasingly evident that the efficiency of the carbonisation process will be much improved by preliminary drying of the fuel.

In Technical Paper No. 178, entitled "Notes on Lignite, its Characteristics and Utilisation," [2] Mr S. M. Darling refers thus to the use of lignite :—

"Because of the inherent shortcomings as fuel in the raw lignite itself, one can safely say that it will never be much used in its natural state. The one fact of containing 30 per cent. water would of itself prevent use elsewhere than in the immediate vicinity of the mine. Therefore the treatment or carbonisation of the lignite, which is absolutely essential to its more general use, is strictly in accordance with modern scientific research. We are simply of necessity starting now to do with lignite what will be done eventually with all our high volatile coals. Instead of trying to burn raw lignite in the primitive and wasteful ways now employed, the lignite should be so treated as to yield several products, each peculiarly adapted to a particular need, as follows :—

"(1) Dried lignite for use on automatic stokers.

"(2) Powdered lignite from the dried pulverised lignite, for use in cement kilns, under locomotive boilers, and in other large furnaces.

[1] Compiled from Reports of the United States Geological Survey.

[2] Technical Paper 178, "Notes on Lignite, its Characteristics and Utilisation," by S. M. Darling, Department of the Interior, Bureau of Mines, 1919.

"Pulverised lignite can also be used in fuel oil burners in conjunction with fuel oil. An oil mixture [1] containing 30 per cent. of dried and finely pulverised lignite will still act as a fluid, and can be burned as a liquid fuel.

"(3) Dried lignite briquettes for large hand-fired industrial furnaces and heating plants.

"(4) Carbonised lignite, for use in suction gas producers. Tests of carbonised lignite in car load lots have shown it to be an unexcelled fuel for such producers.

"(5) Carbonised lignite briquettes for domestic service, an ideal domestic fuel.

The carbonising of lignite will place the lignite-bearing regions substantially on a par as regards fuel and power with those parts of the country that are favoured with bituminous coal. It will give a better domestic fuel in the way of carbonised lignite briquettes, a better gas producer fuel in the form of carbonised lignite, enormous quantities of gas, to be used to fuel or power purposes, a large tonnage of fertiliser in the form of sulphate of ammonia, and a great amount of oils and tars.

"Indeed the products resulting from the carbonisation of lignite are so numerous and varied that it is difficult to imagine a community which could not use all of such products, or whose needs the products could not be so varied as to fit."

It will be observed that Mr Darling, who has made a close study of the utilisation of lignite, insists upon the importance of carbonisation. While this view is shared by many other authorities and can scarcely be disputed, the following comparative data (Table No. 13) will be of interest as very strikingly showing the improved calorific value of carbonised and briquetted lignite as compared with raw lignite :—

TABLE No. 13

Improvement in the Heat Value of United States Lignites, as the Result of Briquetting

Source.	Field Designation.	Moisture. In Raw Lignite.	In Briquettes.	Removed.	Heat Value per Pound. Raw Lignite B.T.U.'s.	Briquettes B.T.U.'s.	Increase.
		Per cent.	Per cent.	Per cent.			Per cent.
Texas	Pittsburg No. 8	33	9	24	6840	9336	36·5
North Dakota	,, ,, 11	40	12	28	6241	9354	50·0
,, ,,	,, ,, 13	42	10	32	6079	9355	54·0
California	,, ,, 14	40	10	30	6080	9264	52·4

The following comparative figures of analyses,[2] while being incomplete, serve to demonstrate the value of briquetting, while at the same time showing how closely

[1] Known as colloidal fuel.

[2] "Economic Methods of Utilising Western Lignite," by E. J. Babcock. Bulletin 89, U.S. Bureau of Mines.

United States briquetted lignite from the Western States approaches Pennsylvania anthracite in its fuel value.

	Moisture.	Volatile matter.	Fixed Carbon.	Ash.	Heating Value.
	Per cent.	Per cent.	Per cent.	Per cent.	B.T.U.'s.
Lignite as mined	35·01	25·11	34·67	5·21	7,000 to 8,000
Lignite briquettes carbonised	0 to 6	2 to 8	72 to 82	10 to 16	11,500 to 12,000
Anthracite	1 to 5	2 to 6	78 to 92	10 to 15	12,000 to 13,500

In a paper read before the International Railway Fuel Association [1] in May 1920 by Mr S. M. Darling, whose work has already been referred to, the following Table, No. 14, was included showing the products obtained in the carbonisation of lignite :—

TABLE No. 14

Products of Carbonisation of Lignite

Gas per ton of lignite . .	cubic feet	10,000
Oil and tar	gallons	15
Ammoniacal residue . . .	,,	65
Carbon ,, ...	pounds	955

Lignite Gas v. *Coal Gas*

	Lignite Gas.	Coal Gas.
Carbon dioxide	15·9	1·34
Illuminants	3·5	4·42
Oxygen	0·2	0·03
Carbon monoxide	19·5	6·75
Methane	16·1	34·60
Hydrogen	43·9	59·19
Nitrogen	0·9	2·67
Candle power	3·2	16·00
B.T.U.'s per cubic feet . .	440	630

The figures given in this table by Mr Darling may with interest be compared with the following average results of a number of tests with lignites from North Dakota, Montana, Colorado, and Texas, given by Mr E. J. Babcock in "Economic Methods of Utilising Western Lignites" :—Average yield per ton of dried lignite unpurified gas, 11,038 cub. ft.; average calorific value, 396 B.T.U.; retort temperature average, 1498° F.; residue after gas driven off per ton average, 1092 lbs.; proportional amount of residue to total, 54 per cent.

[1] "The Better Utilisation of Sub-Bituminous and Lignite Coals," by S. M. Darling, Fuel Engineer, United States Bureau of Mines.

South Australia.—During the past forty years it has from time to time been reported that coal has been discovered, but in every instance investigation has shown the discovery to be tertiary lignite.

In 1914 a considerable deposit was located at Paradise, Highbury, near Adelaide, at a depth of from 156 to 176 feet. An analysis by Mr W. S. Chapman, Analyst to the Department of Mines, gave the following result :—

Moisture at 105° C.	17·10 per cent.
Hydrogen	3·74 ,,
Carbon	48·28 ,,
Nitrogen	0·30 ,,
Oxygen	16·22 ,,
Sulphur	2·24 ,,
Ash	12·12 ,,
	100·00 per cent.

Calorific value=8184 B.T.U.'s

The author inspected a similar deposit in the same district in 1920, samples then taken gave results substantially in agreement with the above.

At Leigh Creek, 373 miles from Adelaide, there is a large deposit, covering an area of some 42 square miles. In 1917 about 700 tons were raised in order to carry out exhaustive tests.

Analyses of samples from this area gave the following results :—

	Undried. Per cent.	Air Dried. Per cent.
Moisture at 105° C.	21·81–31·55	11·32–18·22
Volatile matter	21·39–33·06	23·26–31·97
Fixed carbon	28·63–39·46	35·69–46·90
Ash	4·79–23·86	5·20–25·04
Sulphur	..	0·10– 0·66

The variation in the percentage composition of the fuel as mined, in successive samples taken from the roof to the floor, is shown in the diagram Fig. 8.

In 1918 a seam of 28 feet in thickness was located at a depth of 418 feet at Bower, 85 miles from Adelaide, on the Adelaide Morgan Railway. A bomb calorimeter test of an air dried sample showed a calorific value of 8652 B.T.U.'s per pound. Other samples tested showed a very high sulphur and ash content.

The Leigh Creek field appears to be the most promising of all the deposits so far investigated.

At the Broken Hill Works of The Associated Smelters Company in 1919 a test of Leigh Creek lignite with a Stirling boiler showed an evaporation of 4·017 pounds of water per pound of fuel burned, from and at 212° F. This test, which was made with a furnace designed for burning bituminous coal, showed that given a suitable

furnace there would be no difficulty in obtaining an evaporation of 5 pounds of water per pound of lignite burned, as compared with an evaporation of 8 pounds of water per pound of bituminous coal.

A distillation test of Leigh Creek lignite gave a gas yield of 5140 cubic feet of

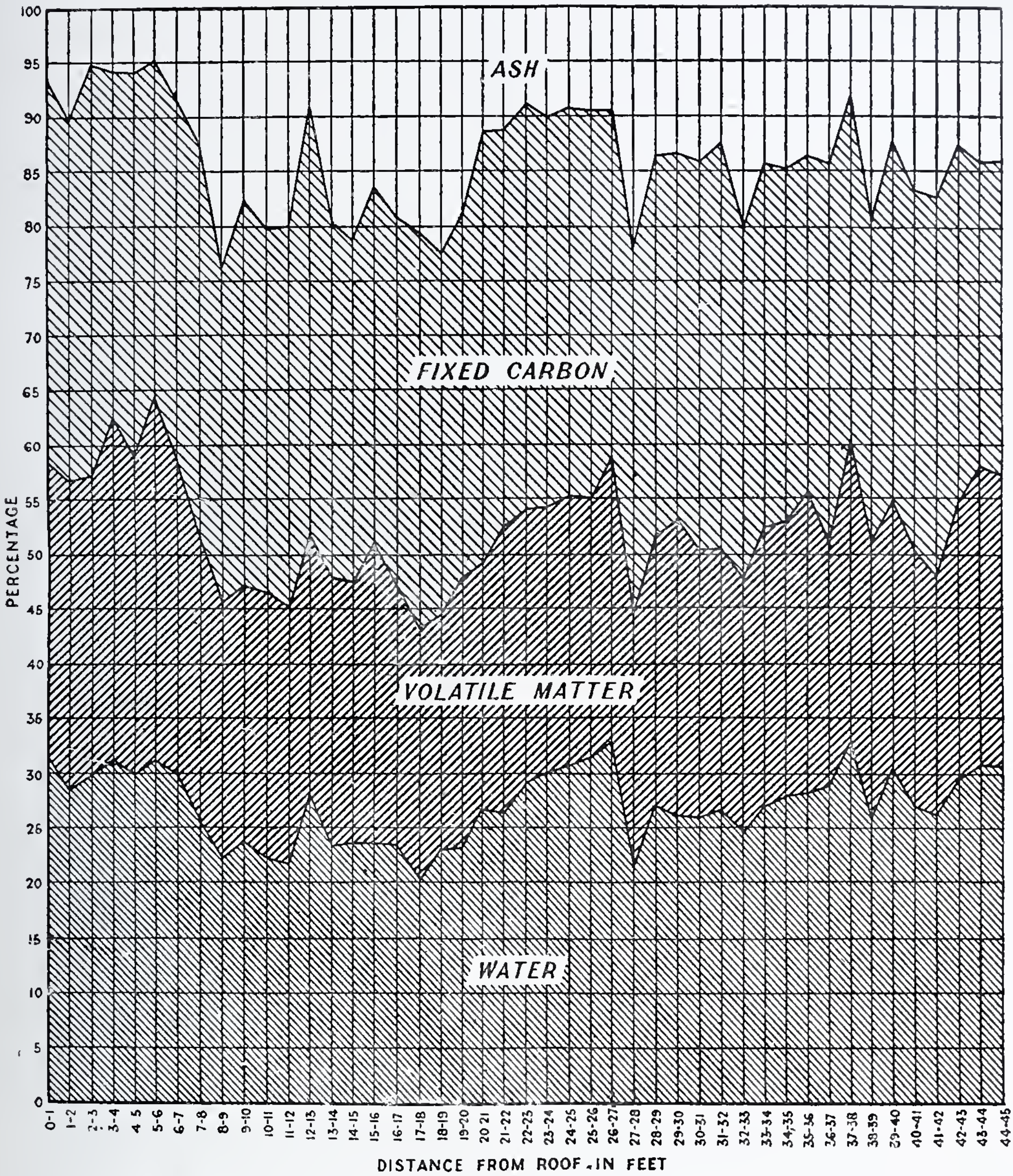


FIG. 8.—DIAGRAM SHOWING VARIATION IN COMPOSITION OF LEIGH CREEK (SOUTH AUSTRALIA) LIGNITE.

346 B.T.U. gas per ton of coal carbonised, the yield of tar was only 1 per cent. as against a yield of 6 per cent. from Newcastle, N.S.W., coal. The residual was very friable, but had a fixed carbon content of 56 per cent.

In 1919 this lignite was given a practical trial in the firing of a large rotary

kiln at the works of The Adelaide Portland Cement Co., Ltd., at Birkenhead. Unfortunately the existing dryer, which was only suitable for removing about 3 per cent. of moisture from Newcastle, N.S.W., coal could only reduce the moisture in the lignite to about 19 per cent.

Nevertheless the ignition and combustion were satisfactory, and although difficulties were experienced in operation, it was shown that from 2 to 2·25 tons of lignite were equivalent to one ton of Newcastle coal.

Realising the importance of developing the fuel resources of the State, in 1920 the South Australian Government decided to allocate a sum of £5000 for experimental work with pulverised Leigh Creek lignite, as also to experiment with other deposits. Since this grant was made some very extensive deposits have been located near the River Murray.

In common with most lignites, South Australian lignite disintegrates very rapidly. The moisture generally seems to vary from about 20 per cent. to 33 per cent., but this can be reduced by air drying to about 15 per cent. The ash varies from 5 per cent. to about 24 per cent.

It is necessary to bear in mind that all trials hitherto conducted in South Australia have not been made under conditions or with apparatus most suitable for the efficient burning of this fuel. In every case the plant used was that designed for the burning of bituminous coal.

During last year some evaporative tests with pulverised South Australian lignite were made in London; the results then obtained were remarkably satisfactory.

To the State of South Australia the successful economic development of the existing fuel resources is of the utmost importance, and there is little doubt that within the next few years a great advance will be made.

Victoria, Australia.—The lignite and brown coal deposits in Victoria are very considerable, and during the past few years there has been much activity in experimental work with a view to important developments upon a large scale.

Following an exhaustive and valuable report [1] by an Advisory Committee, appointed by the Government and presented in 1917, and a subsequent report by the Electricity Commissioners presented to Parliament in 1919, it was decided to proceed with a very comprehensive and important scheme for the utilisation of extensive deposits of brown coal at Morwell, Gippsland, some 90 miles from Melbourne.

Taking six typical deposits of Victorian brown coal, including Morwell, the comparative proximate analyses are as follows :—

	Morwell.[2]	Altona.[3]	Gellion-dale.[1]	Lal Lal.	Dean's Marsh.	Narra-can.[1]
Moisture	53·00	46·80	59·60	56·78	46·86	41·36
Volatile hydrocarbons	24·00	27·60	21·50	21·61	26·65	27·13
Fixed carbon	21·8	20·50	17·30	20·03	30·73	22·36
Ash	1·2	5·10	1·60	1·58	2·56	8·25

[1] Report of the Advisory Committee on Brown Coal, State of Victoria, September 1917.

[2] =bore coal. [3] —partly air dried.

Ultimate analyses of Morwell and Altona samples made at the Geological Survey Laboratory gave the following results :—

	Morwell.		Altona.
Carbon . . .	66·5 per cent.		61·59 per cent.
Hydrogen . . .	4·4 ,,		4·17 ,,
Oxygen . . .	25·5 ,,	(approx.)	25·00 ,,
Nitrogen . . .	0·8 ,,		0·64 ,,
Sulphur . . .	0·3 ,,		0·94 ,,
Ash	2·5 ,,		8·01 ,,

Various samples of brown coal from the Morwell open cut showed the following calorific values, as determined by the Mahler bomb calorimeter :—

	(a)[1]	(b)[2]	(b)[2]	(b)[2]	(b)[2]
Moisture at 105° C. per cent. . . .	35·0	44·0	45·3	46·0	45·4
B.T.U.'s per lb. of coal . . .	7518	6756	6857	6136	6233

In addition to the enormous brown coal deposits at Morwell, there are other important deposits at Altona, Laverton, Gelliondale, and Hedley, Thompson's Bridge and Lal Lal. At Altona is a seam 70 ft. thick, and at Laverton, 2 miles distant, the seam is 140 ft. thick, where it is estimated that the available coal is about 108 million tons.

Between Gelliondale and Hedley is a seam varying from 120 to 193 ft. in thickness, with an overburden of from 30 to 45 ft. This field is estimated to contain about 250 million tons, all obtainable by open cut operation, as illustrated in Figs. 9, 10 and 11.

At Thompson's Bridge, about 5 miles west of the great Morwell open cut, is a seam averaging about 50 ft. in thickness, with an overburden of from 50 to 60 ft. Here the estimated quantity of coal is about 80 million tons.

Westward of the great Morwell open cut, and quite close to the Morwell Power House site, is one seam averaging about 100 ft. in thickness, with an overburden of 40 ft. The anticipated open cut yield here is about 42 million tons.

Beyond this block, which has an area of about half a square mile, are several square miles of coal-bearing country, with an overburden increasing gradually to 100 ft. It is estimated that this district would produce about 100 million tons.

At Lal Lal, some 13 miles from Ballarat, brown coal was first mined fifty years since, and its production still continues at the Lal Lal mine of the Central Victorian Iron and Coal Company. No definite information is available as to the quality, thickness or extent, but there appears to be little doubt that considerable deposits are available.

Considerable quantities of Lal Lal brown coal are now being used in Melbourne in pulverised form for the firing of steam boilers.

The Morwell open cut, hitherto operated by the Victorian Government Mines

[1] =Tested in Geological Survey Laboratory. [2] =Tested in Railway Department Laboratory.

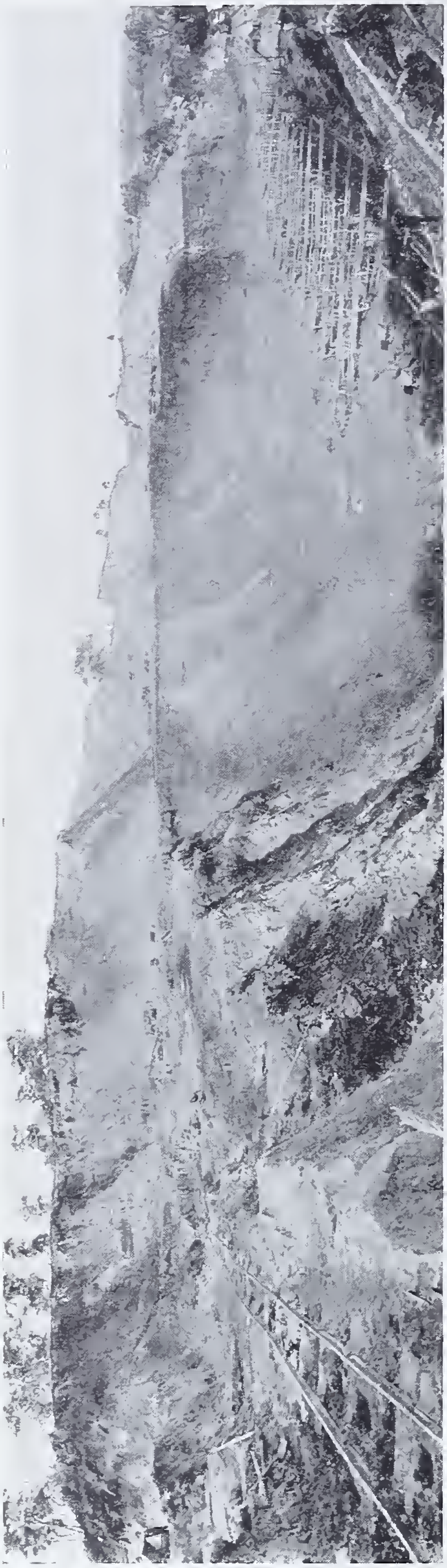


Fig. 9.—Morwell "Open Cut" (Victoria, Australia), Brown Coal Deposit.

Department, and illustrated in Figs. 9, 10 and 11, was visited by the author in 1920 and 1921. It is a remarkable and most interesting example of open cut or quarry mining. The output in 1920 varied from 500 to 1000 tons daily, which was mostly sent by railway to Melbourne, where it was used mainly for industrial purposes.

Fig. 9 is a general view of the open cut, while in Figs. 10 and 11 are shown respectively operation at the coal face, and also the portable railway to the face which is arranged above the railway loading sidings.

In the Report of the Advisory Committee on Brown Coal, State of Victoria, 1917, already referred to, the brown coal was thus described :—"The brown coal from these several localities is a matrix of earthy brown coal with sporadic inclusions of lignite,[1] *i.e.* fragments and even trunks of trees retaining their woody structure. The matrix consists of pollen grains, spore cases, and decomposed vegetable matter. The coal varies in colour between a yellowish brown and black, but it always pulverises to a brown powder. The moisture of freshly mined coal generally exceeds 50 per cent., but much of this is lost on exposure, particularly in warm weather, when a few weeks of air drying would appreciably reduce the moisture content. On continuous exposure the coal shrinks and disintegrates, but large coal from some of the seams (such as Morwell open cut) will not slack seriously for several months if reasonably sheltered from rain and extreme heat. Sulphur is present, partly

[1] Samples which the author obtained at Morwell open cut comprised both brown coal and lignite, the woody character of the latter being very marked and its appearance somewhat resembling Valdarno (Northern Italy) lignite.

Fig. 10.—Morwell "Open Cut" (Victoria, Australia), operating at the Coal Face.
(*From Photograph by the Author.*)

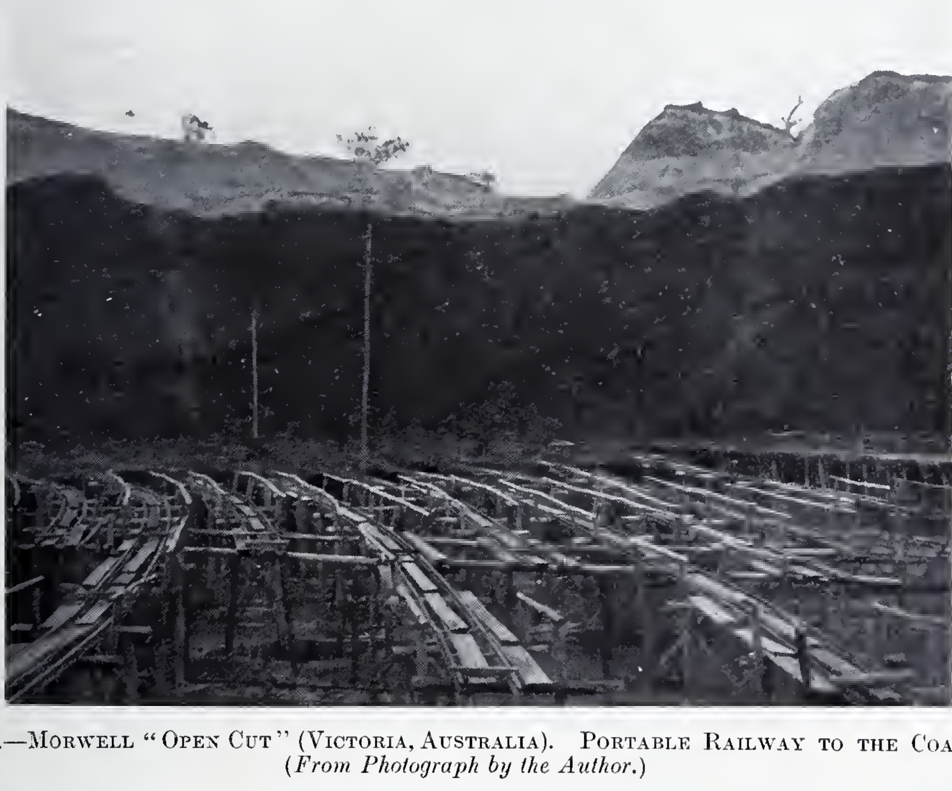


Fig. 11.—Morwell "Open Cut" (Victoria, Australia). Portable Railway to the Coal Face.
(*From Photograph by the Author.*)

organic, partly secondary, in the latter case as iron pyrites. Nodules and veins of mineral resins are more or less common, but not in high percentages."

So far as is known at present the deposits in the neighbourhood of Morwell are of such thickness as are without parallel in any other country in the world. One bore hole showed seven beds of coal within 1000 ft. of the surface, of a total thickness of 781 ft.

Fig. 12 is a map of the State of Victoria showing the location of the brown coal deposits already referred to.

The following steam boiler evaporative tests made in 1909 and 1917 respectively are of much interest as showing the results then obtained with Morwell brown coal under conditions which admittedly were not the most favourable :—

TABLE No. 15

Morwell Brown Coal Tests at Newport (Melbourne) Railway Workshops

Type of boiler	Babcock & Wilcox Water Tube.
Heating surface	2800 sq. ft.
Furnace	Cotton.
Furnace area at fire level	=21 sq. ft.
Furnace area at floor level	=15·75 sq. ft.

	No. 1.	No. 2.	No. 3.
Date of test	15/1/09	18/1/09	19/1/09
Duration of test in hours	8·66	8·66	8·66
Steam pressure per sq. in.	76	74	75
Temperatures—			
Gases leaving boiler, °C.	184	165	170
Feed water, °C.	91	92	91
Fuel—			
Total consumption, lbs.	7830	7927	6842
Average consumption, lbs. per hour	904	915	789
Feed Water—			
Total evaporation, lbs.	37,988	37,423	37,906
Average evaporation, lbs. per hour	4,383	4,320	4,375
Economic Results—			
Evaporation per lb. of fuel as fired	4·85	4·72	5·54
Equivalent evaporation per lb. of coal from and at 100 °C.	5·03	4·89	5·75
Steam percentage used for draught	4·44	4·44	4·44
Moisture percentage in steam	1·25	1·25	1·25
Moisture percentage in coal	34·20	29·38	22·52
Calorific value of fuel as fired B.T.U.	7557	8097	8839
Net efficiency of boiler with coal as fired	61·4	55·7	60·0

FIG. 12.—MAP OF VICTORIA, AUSTRALIA, SHOWING LOCATION OF BROWN COAL DEPOSITS.

TABLE No. 16

Morwell Brown Coal Tests at Melbourne City Council Power House

Type of boiler	Babcock & Wilcox Water Tube.
Heating surface	3654 sq. ft.
Normal rating	12,600 lbs. per hour.
Type of furnace	Semi-producer type, external.
Grate area	49 sq. ft.

	No. 1.	No. 2.	No. 3.	No. 4.
Date of test	14/8/17	15/8/17	17/8/17	20/8/17
Duration of test in hours	6·5	6·0	6·5	6·0
Steam pressure per sq. in.	163	163	164	160
Temperatures—				
Gas leaving boiler, °C.	266	261	300	288
Feed water	97	97	96	100
Steam, °C.	273	271	264	260
Pre-heated air supply, °C.	89	87	90	83
Fuel—				
Total consumption in lbs.	28,672	20,832	30,688	25,760
Average consumption in lbs. per hour	4,412	3,472	4,721	4,293
Average consumption in lbs. per sq. ft. of grate per hour	90	70·9	96·4	87·6
Feed Water—				
Total evaporation in lbs.	101,000	72,300	104,500	92,700
Average evaporation in lbs. per hour	15,540	20,050	16,080	15,450
Economic Results—				
Evaporation per lb. of fuel as fired	3·52	3·47	3·41	3·60
Evaporation per lb. of fuel from and at 100° C.	4·01	3·95	3·86	4·04
Moisture percentage in coal	44·0	45·3	46·0	45·4
Calorific value of coal, B.T.U.	6,756	6,857	6,136	6,233
Efficiency of boiler and air heater with coal as fired	57·3	55·6	60·7	62·6

Morwell Brown Coal (see Table 17)

Mines Department, Melbourne,
September 24th, 1917.

Tests made by the Chief Mining Inspector at the Government Timber Seasoning Works, Newport,[1] with the Owen type of firebar, designed to burn brown coal in the ordinary furnace of the boiler.

[1] The author is indebted to Mr Merrin, Chief Inspector of Mines, for details of these tests.

TABLE No. 17

Results of Tests

		Temperatures.			Pressures.								
Fuel.	Period of test.	Stoke hole. Deg. F.	Feed water. Deg. F.	Flue gases. Deg. F.	Baro-meter.	Boiler pressure.	W.G. at base of stack.	Condi-tion of fire.	Smoke observa-tions.	Total water evap-orated. lbs.	Total coal used. lbs.	Water evaporated from and at 212° F. per lb. of fuel mean.	Pounds of fuel per hour per sq. ft. of grate surface.
Brown coal (1)	8 hrs.	D. 62·5 W. 56·4	51	462	30·01	81	0·28″	Good fine ash only	No smoke to light smoke	19,220	6,616	3·62	31·61
,, ,, (2)	8 ,,	D. 72 W. 63	51	441·5	29·69	84·5	0·24″			17,210	5,644		
,, ,, (3)	$7\frac{1}{2}$,,	D. 69·6 W. 61·6	53	385	29·77	75	0·26″			17,350	5,600		
Wonthaggi large coal	8 ,,	D. 64·7 W. 56·3	50·5	406	29·91	83·3	0·21″	Good ash and clinker	Smoke black to moderate	16,940	2,744	7·41	14·3

The object of the tests was to determine the efficiency of this type of firebar in its relation to :—

(*a*) The condition of the fire, and the combustion of brown coal.
(*b*) The quantity of brown coal consumed per sq. ft. of grate by natural draught.
(*c*) The heat value for steam purposes of the brown coal measured relatively to that of Wonthaggi large coal (now being supplied to the public).

The results of the tests under the foregoing headings were briefly :—

(*a*) The coal did not pack in the grate, but remained open, and underwent vigorous combustion.
(*b*) Using the same grate area, and with natural draught, the increased quantity of brown coal consumed enabled the necessary head of steam to be maintained to run the seasoning plant.
(*c*) A quantity of 2·05 tons of brown coal was found to be equivalent to 1 ton of Wonthaggi large coal, at costs in Melbourne of brown coal (10s. per ton)=20s. 6d., and Wonthaggi coal=23s. 8d.

Particulars of Tests

Class of boiler=Underfired Multitubular, length 14 ft., diameter 6 ft.

Tubes=60 4-in. diameter, fire grate area=24 sq. ft., heating surface=1057 sq. ft., maximum working pressure=100 lbs.

Note.—The brown coal was burnt on Owen's firebars and the Wonthaggi large coal on ordinary firebars.

In December 1918, the Victorian Government passed an important Act creating the Electricity Commissioners. This Act was followed in 1919 by the passing of the Appropriation Act, providing the necessary funds, and authorising the development of the brown coal deposits at Morwell.

A large power station is now in course of erection at Yallourn, Morwell, which will have an initial capacity of 62,500 k.w., the steam boilers, 12 in number, each having a normal evaporative capacity of 70,000 pounds of water per hour, will be mechanically fired with brown coal. It is anticipated that the power station, for which all contracts have been placed, will be in operation early in 1924.

The electric energy will be transmitted to Melbourne, a distance of about 90 miles, at 132,000 volts, and supplied in bulk at 20,000 volts to various undertakers holding electricity orders, and also to large consumers.

It is anticipated that electric energy will be available in Melbourne at a price which could only be equalled if imported coal were delivered at the generating station at about 15s. per ton. In July 1920 the price of imported New South Wales slack on the wharf at Melbourne was about 26s. 9d. per ton.

At Morwell it is expected that it will be possible to place brown coal in the power house bunkers at a cost of rather less than 3s. per ton.

In addition to the supply of electric energy from Morwell, a complete briquetting plant is being installed with a view to producing standard briquettes for domestic and possibly also industrial consumption.

The price of large house coal from New South Wales in the winter of 1920 was about 35s. per ton delivered on the wharf at Melbourne. Brown coal briquettes can be produced and sold at a very much lower figure, and there is little doubt that a considerable and increasing demand for this fuel will be quickly developed.

The Morwell scheme is an ambitious one, and is probably by far the most comprehensive and important project yet launched for the utilisation of high moisture fuel.

It is confidently anticipated that this enterprise will have far-reaching and beneficial effects in the promotion of industrial expansion in Victoria, which State hitherto would appear to have been hampered in industrial development by expensive coal and irregular supplies.

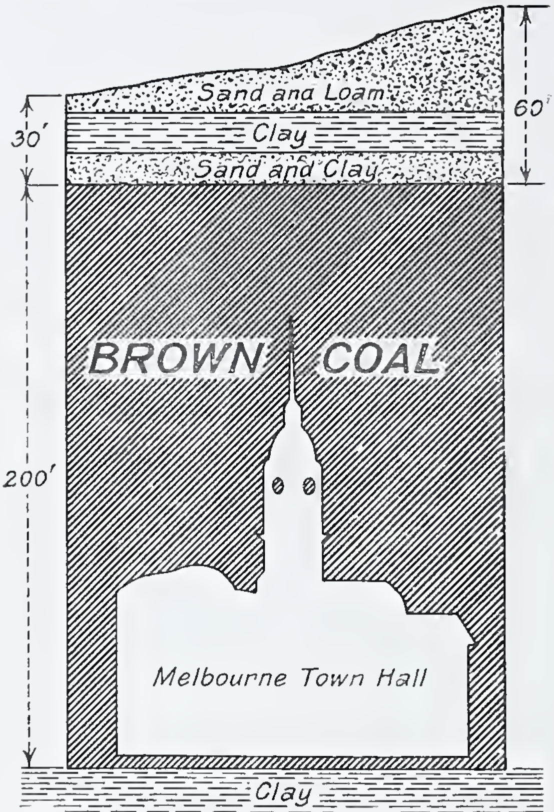


Fig. 13.—Magnitude of the Victorian Brown Coal Deposits.

While the Morwell brown coal is undoubtedly heavy in moisture content, the author was most favourably impressed by the facts (1) that it is a uniformly clean fuel—the percentage of ash varying from 1 per cent. to 2 per cent.; (2) that considerable quantities, even under unsatisfactory conditions, are being used in place of bituminous coal; and (3) the facility with which the fuel is mined, the extraordinary thickness of the seams, the uniform quality, and the enormous extent of the available deposits.

The magnitude of the lignite deposits is graphically shown in Fig. No. 13.

Western Australia.—Lignites and brown coal, mostly of poor quality, are to be found in various parts of the State, but very little active work has yet been done in connection with any deposit.

No geological surveys have so far been undertaken, such as would enable any estimate to be made as to the area or quantity available.

The development of collie coal has been so satisfactory as to render unnecessary the exploitation of other and lower grade fuels.

A sample of Ledger (Western Australian) lignite analysed in this country in 1922 gave the following result :—

Fixed carbon	46·59 per cent.
Volatile matter	31·20 ,,
Moisture	17·88 ,,
Sulphur	0·27 ,,
Ash	4·06 ,,

New Zealand.—Large deposits of lignite and brown coal are available in the Dominion of New Zealand, and while these are now being extensively worked they must in the near future become of much more importance. It is estimated that of the total coal reserves of New Zealand about 60 per cent. are lignite and brown coal. The estimated [1] proved and probable reserves are as follows :—

	Proved. Millions of Tons.	Probable. Millions of Tons.
Brown coal	234·5	728
Lignite	278·5	839

The principal producing areas are :—

Waikato.—Taupiri Coal Mines, Ltd., Pukemiro Collieries, Ltd., and the Waipa Railway & Collieries, Ltd.

Canterbury.—(Homebush) Kaitangata and Nightcaps.

The approximate total output of these fuels to December 31st, 1918 was :—

Brown coal	14,480,157 tons.
Lignite	2,541,678 ,,
	17,021,835

During the same period the approximate total output of bituminous and semi-bituminous coal was 31,705,005 tons. It will be seen from the following proximate analyses,[2] Table No. 18, that generally the brown coal and lignites of New Zealand are of excellent quality :—

TABLE No. 18

Proximate Analyses of New Zealand Brown Coal and Lignites

Description.	Locality.	Fixed carbon.	Volatile matter.	Moisture.	Ash.	Sulphur.	Calorific value (calories).	Evaporative efficiency as determined by calorimeter.
Brown coal	Taupiri [3] Taupiri, extended	43·73	42·12	11·72	2·43	0·32	6129	11·44
,, ,,	Nightcaps, Southland	41·20	38·72	17·56	2·52	0·28	5737	10·70
,, ,,	Kaitangata	38·00	39·96	18·22	3·82	0·40	5553	10·36
,, ,,	Homebush, Canterbury	31·83	41·82	23·15	3·20	0·41	4953	9·24

[1] Report of the Board of Trade, N.Z., on the Coal Industry, May 20th, 1919.

[2] "Proximate Analyses," by Dr Maclaurin, Dominion Analyst.

[3] A sample tested in this country gave the following analysis :—

Fixed carbon	43·91 per cent.
Volatile matter	38·50 ,,
Moisture	14·84 ,,
Ash	2·48 ,,
Sulphur	0·27 ,,

TABLE No. 18—*continued*

Description.	Locality.	Fixed carbon.	Volatile matter.	Moisture.	Ash.	Sulphur.	Calorific value (calories).	Evaporative efficiency as determined by calorimeter.
Lignite ,,	Bannockburn Cromwell Central Otago	23·75	43·83	26·12	6·30	0·32	4291	8·00
,,	Mataura, Southland	19·01	40·77	36·65	4·57	0·31	3789	7·07

In the charging of differential railway rates the railways of New Zealand encourage the use of these fuels. The highest rates are charged upon imported Australian coal, reduced rates on New Zealand bituminous coal, and the lowest rates on brown coal and lignite.

Important deposits of lignite exist in Czecho Slovakia, while in Denmark during and since the War the output of brown coal has averaged about 90,000 tons per annum. Dutch lignite is referred to in another chapter in which waste fuels are discussed. Lignite has been, and still is, mined in Bohemia, Greece and Austria, as also in Italy, where during 1922 the production was 1,840,000 tons.

The following are analyses of Bohemian and Grecian lignites :—

Bohemia

Moisture.	Ash.	Combustible matter.	Calories.
19·90	2·55	77·55	5546
27·83	2·91	69·26	4775
36·56	3·21	60·03	4013

Greece

Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Ash.	Moisture.
48·86	4·24	0·65	2·07	10·40	10·08
38·09	4·03	2·51	9·21	10·44	13·72
40·24	3·32	0·97	0·64	7·59	18·69

Extensive deposits of lignite are available in the Malay Peninsula, India and Burma. The following recent analyses of Palana (Indian) lignite are of interest, as this fuel is now being burned in hand-fired furnaces of both Lancashire and Economic boilers for steam generation in connection with electricity supply.

Palana Lignite [1]

	Volatile matter.	Fixed carbon.	Moisture.	Ash.	Specific gravity.
As received	25·13	24·92	45·60	4·35	1·19
Air-dried	34·74	34·44	24·80	6·02	. .
Dried	46·20	45·80	. .	8·00	. .

[1] Comparative tests of Palana lignite briquettes and Bengal locomotive coal have shown, for an equivalent evaporation, a consumption of 1·744 lbs. of lignite to 1 lb. of coal. (See *Transactions of the Mining and Geological Institute of India*).

Ultimate Analysis

DRIED SAMPLE

Carbon	62·56	per cent.
Hydrogen	5·15	,,
Nitrogen	0·76	,,
Oxygen, by difference	23·03	,,
Ash	8·50	,,

Calorific value of dried sample = 11,579 B.T.U.

The valuable experimental and research work done by Professor W. A. Bone [1] in the pre-drying of high moisture fuels has very clearly demonstrated their improved calorific value when the moisture content is materially reduced, and there is but little doubt that in the future development of lignite and brown coal the use of waste heat for reducing the moisture content will play an important part.

Points of importance to be observed in the burning of Lignite and Brown Coal for Steam Generation

The results obtained in steam generation with high moisture fuels, even with furnaces and combustion chambers designed and arranged for the burning of bituminous fuels, has conclusively shown that lignite and brown coal can be burned, but with a thermal efficiency which rarely exceeds 60 per cent.

This will be quite clear from the foregoing details of evaporative tests at Ottawa and in Melbourne.

Further, it has been demonstrated that with furnaces specially designed for the burning of these fuels no difficulty is experienced in obtaining the rated boiler output, and also a thermal efficiency which will bear reasonable comparison with good average results obtained when burning bituminous coal.

The question of furnace design is an important one inasmuch as the design and efficiency of the furnace are the determining factors in the performance of the boiler.

It will, for instance, be obvious that if these high moisture fuels are burned under the same conditions as ordinary coal, and with rates of combustion varying from 15 to 25 lbs. per sq. ft. of grate surface per hour, the boiler output or capacity will be so reduced that in order to obtain the output of steam desired, two or even three boilers may be required to give the same evaporation as would be obtained from one boiler fired with bituminous coal under good conditions.

If these high moisture fuels are to be efficiently utilised, if, in short, they are to displace coal, or render its use unnecessary, they must be burned under such conditions that, with a boiler of a given heating surface, it shall be possible to

[1] Experiments at Morwell with the pre-drying apparatus patented by Professor Bone, and manufactured by the Underfeed Stoker Co., Ltd., have shown a rate of combustion of 94 lbs. per sq. ft. of grate per hour, an evaporation of 8·7 lbs. of water per sq. ft. of heating surface per hour, and a furnace temperature of 2100° F.

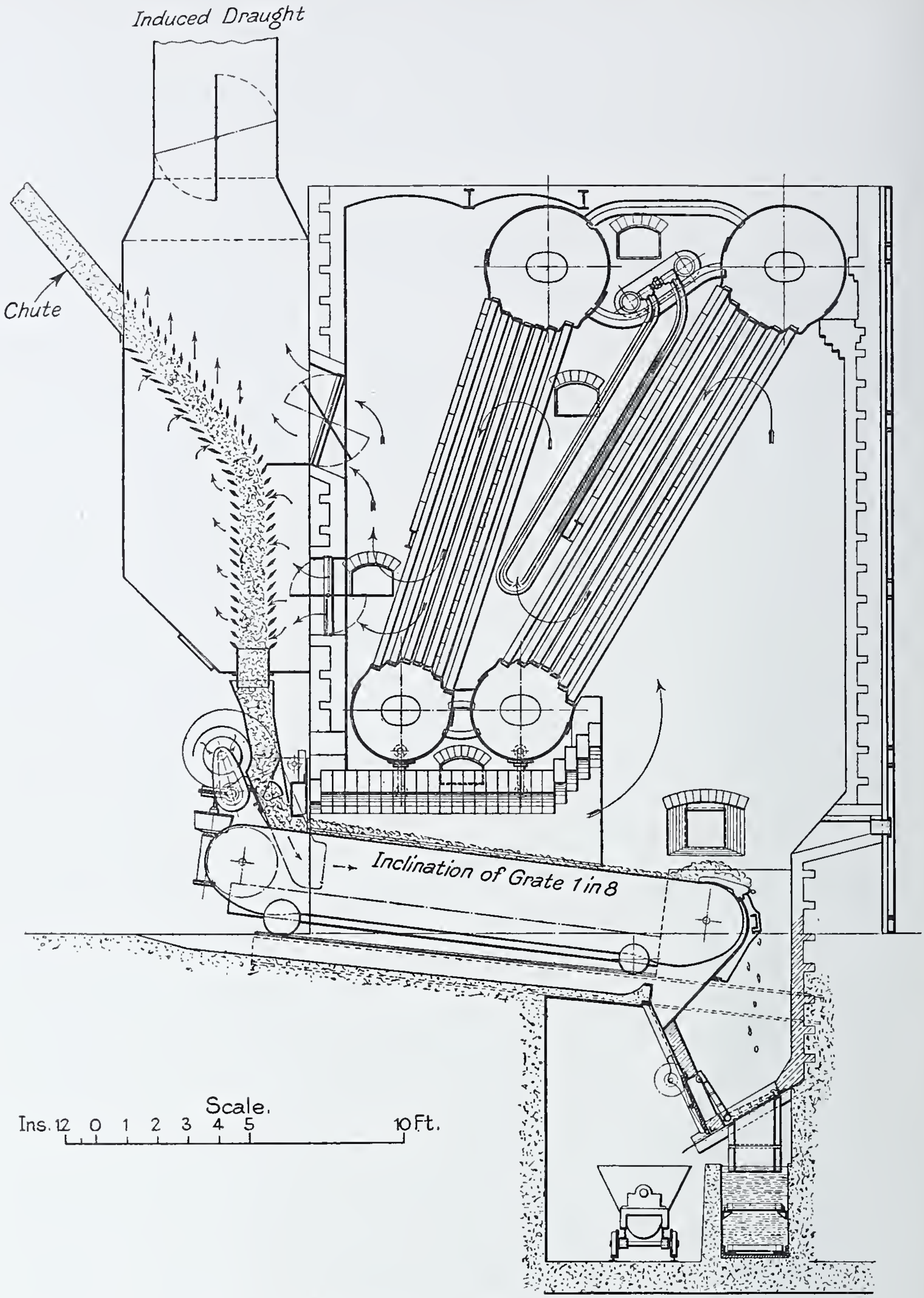


Fig. 14.—Patent Dryer for Brown Coal and Lignite as applied to a Thompson Water Tube Boiler.

burn lignite or brown coal efficiently at such rates of combustion that an equivalent boiler output can be secured.

For the efficient utilisation of these fuels for the generation of steam the only suitable boiler is the water tube type. With no other type of boiler is it possible to provide either the most suitable furnace equipment or the conditions which are imperative for the efficient combustion of high moisture fuels.

Not only does the design of the water tube boiler lend itself to the provision of a suitable type of grate and a sufficiency of grate area, but what is even more

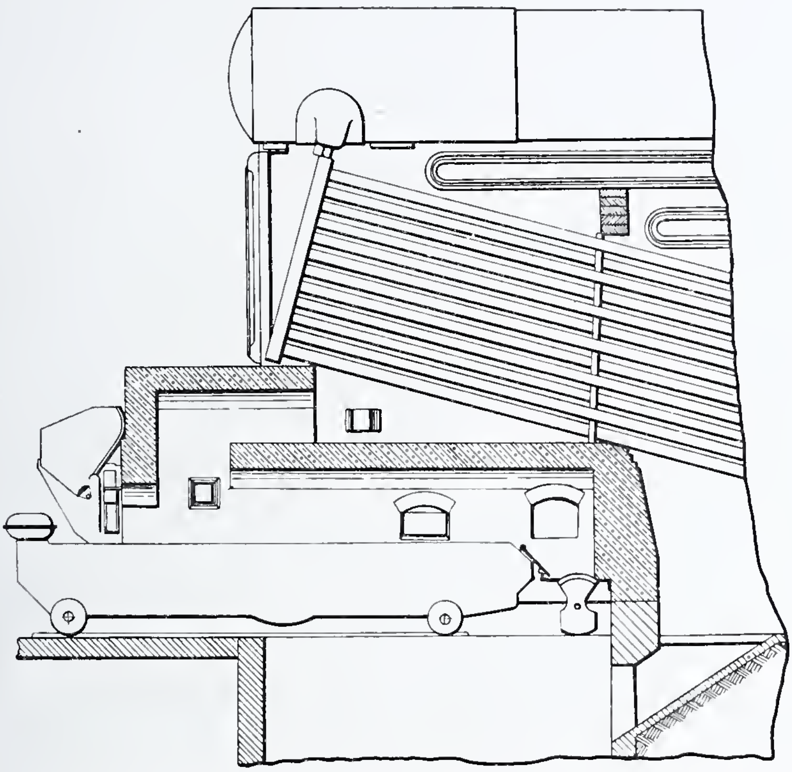


Fig. 15.—Arrangement of Furnace Arches for the Burning of Morwell Brown Coal in connection with a Babcock & Wilcox Boiler and Chain Grate Mechanical Stokers.

important is that this type of boiler can be so set as to provide suitable combustion space.

Apart from the question of air supply the problem of burning these fuels with a reasonable efficiency hinges upon the type and arrangement of the grate and the provision of suitable combustion area.

Although it has been assumed that a powerful draught is necessary, actually this is not so. A furnace draught of 0·5 ins. W.G. will burn as much as 40 lbs. per sq. ft. of grate per hour.

The use of hot air for combustion is undoubtedly advantageous, but the pre-drying and upgrading of the fuel, as advocated by Professor Bone, will show a much greater increase in the thermal efficiency, and accordingly gives a greater return upon the capital expenditure involved. In Fig. 14 is shown the arrangement of

the patent dryer already referred to in connection with Professor Bone and the Underfeed Stoker Company, Ltd. The application is shown in connection with a Thompson water tube boiler equipped with underfeed self-contained mechanical stokers arranged for burning lignite or brown coal.

Up to the present time neither the pre-heating of the air supply nor the pre-drying of the fuel has been adopted to any extent, mainly because it has been shown that very good results in steam generation are obtainable with both fresh and air-dried fuels, with the air supply at atmospheric temperature.

While it is possible with efficient air-drying to reduce the moisture content to 15 per cent., it will be obvious that the air-drying of these fuels presents the same

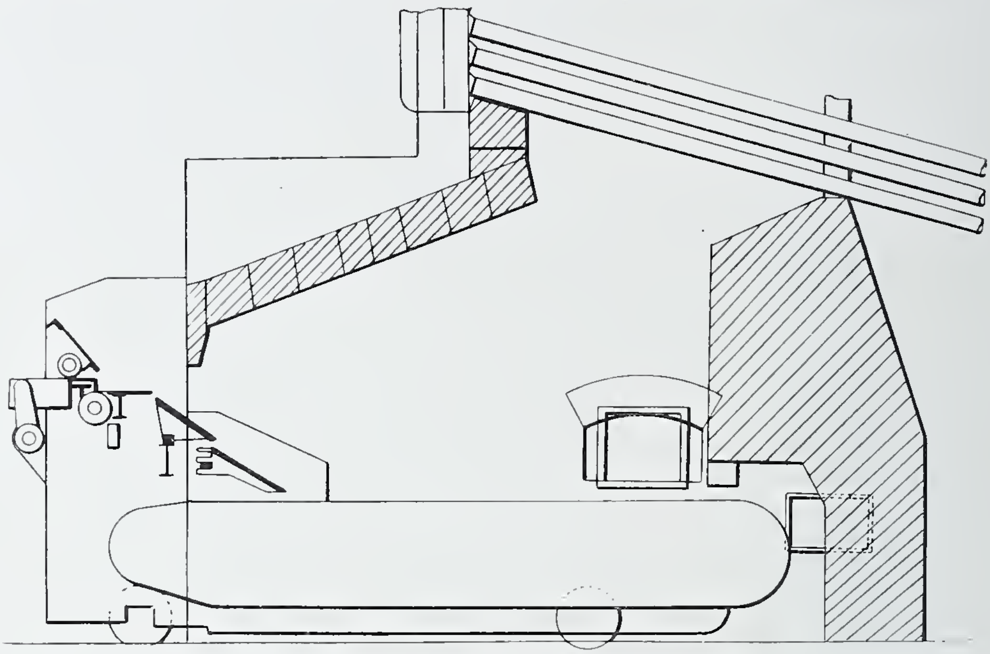


Fig. 16.—Inclined Drying Plates for High Moisture Fuels as arranged with Chain Grate Mechanical Stoker.

difficulty as peat, inasmuch as such drying can only be seasonal and is limited by climatic conditions.

Preferably all high moisture fuels should be machine fired, while very efficient results are being obtained with chain grate [1] and travelling grate mechanical stokers ; a step grate would also fulfil all requirements, but suitable arches are essential.

Fig. 15 illustrates a Babcock and Wilcox boiler with chain grate stoker, the arches being specially arranged for burning brown coal.

Whichever type of mechanical stoker may be used, it should be specially arranged to suit the requirements of the fuel. The ordinary hopper gravity feed on to a horizontal plate or fuel bed does not present the best conditions.

With some mechanical stokers of the coking type for the burning of coking coal a solid or perforated horizontal coking plate is provided. Under forced draught

[1] With chain grate stokers the ratio of grate area to heating surface should not be less than 1 to 30.

TABLE No. 19

Evaporative Tests with Lignite (Holland and Germany) fired with Pluto Mechanical Stokers

1. Test at	Dutch Government mines	Badische Soda W. Anilin Fabriken	Papierfabriek, Gelder & Zn, Velsen	Power Plant, Rotterdam	Krupp, Berndorf
2. Date of test	20/1/1921	29/11/1919	4/10/1918	19/3/1919	11/8/1911
3. Duration of test (hours)	8	8	8·55	8	8
4. Type of boiler	Borsig water tube	Garbe vertical water tube	Garbe vertical water tube	Babcock & Wilcox (2)	Water tube
5. Heating surface of boiler, sq. ft.	3,350	5,910	4,300	7,160	1,720
6. ,, ,, superheater, sq. ft.	. .	1,290	1,290	1,520	323
7. ,, ,, economiser, sq. ft.	No economiser	3,340	3,860	5,580	. .
8. Type of mechanical stoker	Pluto	Pluto	Pluto	Pluto	Pluto
9. Total grate area, sq. ft.	160	275	177	236 (each)	64·5
10. Fuel	Lignite	Lignite	Lignite	Lignite	Lignite
11. Percentage of moisture	52·5	54·3	57	54·9	30·77
12. ,, ,, ash	6·5	6·0	5·5	7·9	23·53
13. ,, ,, volatile matter	. .	10·5	22·77	23·6	. .
14. Heating value, B.T.U.'s	3,691	4,196	3,750	3,499	4,117
15. Weight of fuel used, lbs.	54,560	107,008	75,152	108,680	22,620
16. ,, ,, per hour, lbs.	6,820	13,376	9,394	13,760	2,828
17. ,, ,, per sq. ft. of grate per hour, lbs,	42·6	48·6	53·0	58·3	43·8
18. Total weight of ash and clinker, lbs.	3,350	. .	3,740	3,601	. .
19. Percentage of ,, ,,	6·15	. .	5·0	3·3	. .
20. Temperature of feed water to economiser	. .	156·2° F.	92·1° F.	97·9° F.	. .
21. Temperature of feed water from economiser	No economiser 161·6° F.	257·0° F.	221·4° F.	230·9° F.	244·4° F.
22. Total water evaporated, lbs.	113,960	295,086	133,896	234,520	68,992
23. Water evaporated per hour, lbs.	14,245	36,886	20,624	29,385	8,624
24. Water evaporated per hour per sq. ft. of heating surface, actual	4·25	6·24	4·8	4·1	5·01
25. Water evaporated per sq. ft. of heating surface per hour from and at 212° F.	4·25	6·73	6·24	4·4	4·9
26. Steam pressure (average) lbs. per sq. in., absolute	186	249·5	244·6	182	189·4
27. Temperature of superheated steam	509° F.	685·4° F.	609·8° F.	550·4° F.	609·2° F.
28. ,, ,, saturation of steam	375° F.	496·3° F.	492·8° F.	374° F.	376·7° F.
29. ,, ,, gases after boiler	563° F.	644° F.	611·6° F.	492·8° F.	. .
30. ,, ,, gases after economiser	. .	390·2° F.	298·4° F.	240·8° F.	408·2° F.
31. Draught above grate	0·06 in.	0·074 in.	0·1 in.	. .	. .
32. ,, after boiler	0·48 in.	0·308 in.	0·42 in.	0·41 in.	. .
33. ,, after economiser	. .	. .	0·6 in.	0·58 in.	. .
34. Percentage of CO_2 in gases after boiler	13	14·25	13·3	13·2	12·6
35. Water evaporated per lb. of fuel, actual	2·09	2·76	2·44	2·16	3·05
36. ,, ,, ,, from and at 212° F., thermal efficiency	2·09	2·98	2·7	2·8	2·98
37. Net working efficiency of boiler only	60·8	64·9	66·34	60·2	72·3
38. ,, ,, superheater only	4·3	7·9	7·78	5·9	9·3
39. ,, ,, economiser only	. .	6·6	8·42	8·1	. .
Total efficiency	65·1	79·4	82·54	74·2	81·6

TABLE No. 20

Evaporative Tests with Brown Coal (Hungary and Austria) fired with Pluto Mechanical Stokers

Test at	Königshofer Cement Works	Gun Works, Cyör	Juliusschaeht, Brux	Hospital, Graz
Date of test	May 5th, 1911	July 27, 1916	June 6th, 1917	Dec. 1st, 1912
Duration of test (hours)	7 hrs. 8 min.	7 hrs. 35 min.	8 hrs. 18 min.	6 hrs. 15 min.
Type of boiler	Water tube	Garbe	Water tube	Water tube
Heating surface of boiler (square metres)	2,208	545	225	216
,, ,, superheater ,, ,,	255	180	50	..
,, ,, economiser ,, ,,	2,180	400	..	..
Pluto meehanical stoker.				
Total grate area (square metres)	..	23	8·81	8·05
Effective grate area ,, ,,	..	20·39	7·59	6·89
Fuel	Bohemian Brown Coal	Hungarian Brown Coal	Hungarian Brown Coal	..
Pereentage of ash	..	7·9	9·3	..
,, ,, moisture	25·28	17·4	32·4	..
Heating value (ealories)	5,015	4,835	3,787	3,925
Total weight of fuel used	11,500 kgs.	16,396 kgs.	9949·7 kgs.	8·200 kgs.
Fuel burned per hour	825·35 ,,	2,165 ,,	1,191 ,,	1,312 ,,
Fuel burned per square metre of grate per hour	125 ,,	106·2 ,,	156·9 ,,	164 ,,
Weight of elinker and ash	326 ,,	1,177 ,,	455·5 ,,	945 ,,

Percentage of clinker and ash	2·8 %	7·2 %	4·22 %	11·52 %
Combustible in residuals	0·47 ,,	4·3 ,,	6·7 ,,	1·04 ,,
Temperature of feed water to economiser	65·3° C.	22·2° C.	42·94° C.	59·5° C.
Temperature of feed water leaving economiser	123·75° C.	109° C.	..	..
Total feed water used	67,060 kgs.	82,480 kgs.	37,960 kgs.	33,410 kgs.
Steam pressure (gauge)	14·8 kgs.–cm.^{2}	15 kgs.–cm.^{2}	11·33 kgs.–cm.^{2}	9·94 kgs.–cm.^{2}
Temperature of superheated steam	400° C.	350° C.	290·06° C.	..
Heat units absorbed in economiser (calories)	58·45	76·8	..	..
,, ,, ,, boiler (calories)	547·35	572·2	625·86	602·83
,, ,, ,, superheater (calories)	108·9	82·8	55·9	..
Heat units supplied to evaporate and superheat 1 kg. of feed water	714·25	731·8	681·76	602·83
Temperature of air	20° C.	21·6° C.	22·1° C.	16° C.
Temperature of gases after economiser	185·9° C.	230° C.	..	..
Temperature of gases leaving boiler	311·3° C.	363° C.	293° C.	416° C.
Percentage of CO_2 in gases	10·9 %	11·5 %	12·65 %	10·6 %
Actual evaporation, kgs. of water per kg. of fuel	5·695	5·10	3·82	4·075
Efficiency of boiler	61·728 %	60·5 %	62·91 %	62·70 %
,, ,, economiser	7·030 ,,	8·2 ,,	..	..
,, ,, superheater	12·83 ,,	8·9 ,,	5·62 %	..
Total efficiency	81·138 ,,	77·6 ,,	68·53 ,,	62·70 %
Chimney loss	12·83 ,,	8·9 ,,	14·38 ,,	24·82 ,,
Loss in ash and clinker	0·013 ,,	0·6 ,,	0·51 ,,	0·12 ,,
Loss due to radiation	5·15 ,,	9·9 ,,	16·18 ,,	12·36 ,,

conditions this plate has been found to be of much value in aiding or accelerating ignition.

With a similar object in view substantial and sharply inclined plates provided for the burning of high moisture fuels would exercise a very beneficial spreading and drying effect upon the descending fuel, securing a more rapid liberation of the moisture and accordingly accelerating the ignition.

The inclined plates suggested are illustrated in Fig. 16, and have already been put into satisfactory use.

The provision of ample ignition arch surface is essential. Not only is it necessary to provide a front arch of ample length, but the results will be materially improved by the provision of a rear arch arranged at a rather lower level. All arches should preferably be as flat as possible and of the suspended type, set as low as practicable.

The cubic capacity provided in the furnace must be adequate. Even in cases where boilers have been specially set for the utilisation of high moisture fuels, and where it was assumed that ample combustion area has been provided, it has been found that the area allowed could have been increased with advantage. Owing to rapid disintegration in the fire it is important that the design and arrangement of the grate should be such that the sifting through of combustible into the ashpit is reduced to the minimum.

It must not be assumed, even when high moisture fuels are burned under good conditions, that an overall thermal efficiency can be obtained as high as is possible when burning coal under equally favourable conditions.

With a well-designed and carefully operated plant using dried fuel a thermal efficiency of from 65 to 70 per cent. can be obtained when burning fuel at the rate of from 60 to 90 lbs. per sq. ft. of grate per hour, with furnace temperatures varying from 2000° F. to 2100° F.

In Tables Nos. 19 and 20 (see pages 61–63) are included details of evaporative tests with lignite and brown coal, in Holland, Germany, Hungary and Austria. In each case the mechanical stokers used were of the Pluto (Dutch) type, which will be illustrated and described in a succeeding chapter.

As an alternative method of firing, the pulverisation of lignite and brown coal has been much advocated. With a view to carrying out tests upon a practical scale the State Electricity Commissioners of Victoria decided to instal a pulverised fuel plant at Newport Power Station, Melbourne.

Given a suitable boiler, arranged and set for this system of firing, there is no doubt that efficient results may be obtained. The principal difficulties presented are (1) the satisfactory drying of the fuel and the cost of drying, (2) the actual calorific loss involved in drying a fuel possessing the characteristics of lignite or brown coal, and (3) the interception of the dust carried in suspension in the gases.

A variation in the moisture content has a greater effect upon the results than can be accounted for merely by the thermal loss due to the increased moisture percentage. There would appear to be a critical point in the moisture content above

which the loss increases rapidly. This is doubtless due to the reduction in the furnace temperature and the retarding of ignition.

It has been suggested that pulverised lignite or brown coal [1] could be advantageously used for the firing of locomotives.

With this the author is not in agreement. The conditions presented for the combustion of such pulverised fuel in locomotive boiler fireboxes are unsatisfactory, and this applies also to all boilers of the fire tube type.

[1] In this connection it is interesting to note that General Order No. 107, Board of Railway Commissioners, Canada, dated July 14th, 1913, prohibited the use of certain grades of lignite for the firing of locomotives, owing to the emission of dangerous sparks.

CHAPTER IV

PEAT

DURING the past few years the increased cost of coal, and an extreme shortage in some European countries, mainly or entirely dependent upon imported coal supplies, has had the natural effect of stimulating renewed interest in peat development, both for domestic and industrial use.

Peat consists of the fibres of various mosses and other fibrous and aquatic plants. In some samples the origin is clearly defined, while in other samples, of a very dense or earthy nature, it is all but impossible to detect evidence of plant origin.

Ekenberg, who has devoted such close study to peat problems in Sweden, expressed the opinion that to some extent the water in peat is held by a colloidal or gelatinous substance, which he termed hydrocellulose. This substance appears to possess the property of absorbing many times its own weight of water.

The older and more humified peat bogs appear to contain the highest percentage of this gelatinous substance. It is found to the greatest extent in the deepest layers of a bog, decreasing in the upper layers and near the surface.

It is a common experience to find in peat bogs plant fibres and roots, and in some cases remains of cones, fir needles, and trees.

In its natural state, that is, as it exists in the bog, peat usually contains about 90 per cent. of water, which percentage is sometimes exceeded. Even in the case of the most thoroughly drained bog the water is but rarely less than 88 per cent. It may therefore be stated that 100 lbs. of peat as cut from the bog usually contain not less than 90 lbs. of water—which is most tenaciously held—and only 10 lbs. of combustible material.

In order to render this 10 lbs. of combustible available for use as a comparatively dry fuel, the bulk of the 90 lbs. of moisture content must be removed. The problem of its economic removal artificially, or mechanically, has up to the present proved to be exceedingly difficult, if not impossible, and despite the ingenuity and activity of many inventors, several of whom have claimed to have solved the problem, it still awaits solution.

The economic drying of peat is a twofold problem, involving not only the effective and inexpensive removal of the bulk of the high moisture content, but also the use of such means for its removal as may be employed continuously throughout the year, regardless of weather or climatic conditions.

Air drying, by exposure to sun and wind, while being the simplest and most economical process, obviously cannot be a continuous process, inasmuch as it is necessarily limited to a comparatively short period during the year.

The highest authorities are agreed that no alternative system of drying has yet been devised which is economically sound, despite the various claims to the contrary. The failure hitherto to considerably reduce the moisture content at an economic cost, has been, and is, the most serious obstacle to the extended use of peat as fuel. In this connection it may be desirable to quote the opinions of experts who have closely studied the problems involved in peat winning and utilisation.

Mr B. F. Haanel,[1] B.Sc., Chief of the Fuels and Fuel-testing Division, Department of Mines, Canada, in the introductory notes to his very useful and comprehensive work, "Peat, Lignite and Coal," refers thus to artificial drying :—

"It is shown that the artificial drying of peat cannot be accomplished economically, and that to attempt to reduce the water content of the raw peat to below 76 per cent. by hydraulic pressure will result in commercial failure."

Referring to the drying of peat, Professor Pierce F. Purcell, A.M.I.C.E., an acknowledged authority of wide experience, in a lecture on "The Peat Resources of Ireland,"[2] said :—

"Many methods have been tried for the elimination of water from peat, but the most successful is drying by natural atmospheric agencies, wind and sunshine being the chief factors. This method has been practised under one form and another since at least the commencement of the Christian era, and Pliny the elder observed it whilst engaged in the then army of occupation in Germany. This makes it all the more surprising that notwithstanding the advance in science, and in mechanical and industrial operations, the air drying of peat by natural means is the only recognised commercially successful method in use to-day."

. . . "When peat as taken from the bog is subjected to high and long-continued pressure, about three-quarters of the contained water is driven off, and the moisture content is reduced from 90 per cent. to 70 per cent., but even in this condition it is still useless for fuel purposes. This represents the maximum effects of pressure on raw peat, and it is now accepted as a fact that peat cannot be prepared by pressure alone."

. . . "When, however, we take account of the fact that the efficiency of the dryer will not average more than 60 per cent., it can be shown that peat with 83·5 per cent. of water has no practical calorific value, as the 16·5 per cent. of peat is required to evaporate the contained water."

A. Hausding,[3] whose contribution to the technology of peat has been so valuable, in his well-known standard German work, is no less definite on this question :

"Artificial drying of peat,[4] *i.e.* the manufacture of kiln-dried peat, is not economically sound."

"The only method of drying which has hitherto proved satisfactory is air drying."

"Dehydration of peat by compression, even when an electrical current is employed, is unscientific, and does not lead to the goal desired. By strong com-

[1] "Peat, Lignite and Coal," by B. F. Haanel, B.Sc., 1914.

[2] Fuel Research Board, Special Report, No. 2, 1920, "The Peat Resources of Ireland," by Professor Pierce F. Purcell, A.M.I.C.E.

[3] "Handbuch der Torfegewinnung und Torfeverwertung," Berlin, 1917.

[4] "A Handbook on the Winning and the Utilisation of Peat," by A. Hausding. Translated from the third German edition by Hugh Ryan, D.Sc., Professor of Chemistry, University College, Dublin.

pression, even with a pressure of 400 to 500 atmospheres for several hours, the percentage of water in a peat (85) could not be lowered below 63."

The cost of kiln or heat drying, for which some extraordinary claims have been made from the point of view of efficiency in fuel consumption, obviously is not entirely dependent upon the cost of the fuel used to reduce the moisture content to a given point. There are other very important factors which cannot be ignored, such as the capital cost of the drying plant and the cost of handling both the raw and the dried peat.

A further factor of importance is the capacity of the dryer, which must be sufficiently large to accommodate a considerable quantity of raw peat, in order to obtain a relatively small output of dried peat.

When it is possible to employ waste heat, as has been done in connection with one or more plants in Italy, the efficiency of the dryer is not so important. When, however, fuel of any kind has to be used in order to provide the necessary heat, the weight of fuel required and its cost are serious factors.

As Mr B. F. Haanel says in his work,[1] which has already been referred to :—
"Even assuming that dry peat is used for the dryer, for providing the required heat, the consumption may be so high as to be commercially impossible. For instance, assuming that it is desired to produce 100 lbs. of dry peat from 500 lbs. of raw peat containing 80 per cent. of moisture, the consumption of dry peat in the dryer would be approximately 67 lbs., so that the net result would be the production of 33 lbs. of dry peat from 500 lbs. of 80 per cent. moisture peat, or a *net* percentage of 6·66."

Owing to its poor heat conductivity it is possible to char or burn the outside surfaces of peat in a dryer, while only a comparatively small percentage of the contained water is evaporated. The following Table, No. 21,[2] shows the weight of water removed by drying at 10 per cent. stages from one ton of peat, as excavated from the bog (90 per cent. water), in drying to 10 per cent. of water.

TABLE No. 21

Percentage of water in the peat.	Dry peat contents (lbs.).	Water content (lbs.).	Weight of water removed for each 10 per cent. reduction (lbs.).	Weight of material obtained for each 10 per cent. reduction (lbs.).	Total weight of water evaporated (lbs.).
90	200	1800	..	2000	..
80	200	800	1000	1000	1000
70	200	466·7	333·3	666·7	1333·3
60	200	300	166·7	500	1500
50	200	200	100	400	1600
40	200	133·3	66·7	333·3	1666·7
30	200	85·7	47·6	258·7	1714·3
20	200	50	35·7	250	1750
10	200	22·2	27·8	222·2	1777·8

[1] "Peat, Lignite and Coal," by B. F. Haanel, B.Sc., 1914.

[2] Bulletin 376, "Peat Deposits of Maine," by Edson, S. Bastin and Charles A. Davis. United States Geological Survey. 1909.

Air-dried peat has been used in many European countries for domestic purposes for many centuries past: its use has been mainly limited to the vicinity of bogs. The peat, being cut from the bog in blocks, is partially dried on the bog under favourable weather conditions, and then stored under cover for use as required.

For any operations upon a commercial scale the use of peat cutting and handling machinery is essential. Unless labour-saving devices are employed, it may be said to be commercially impossible to cut and handle peat excepting upon a very limited scale.

Regarding peat as a low grade fuel, which must be sold at considerably below

Fig. 17.—Abjörn Andersson's Peat Dredging Machine.

the cost of coal—if it is to displace or render the use of coal unnecessary—it will be obvious that labour-saving apparatus must be employed so far as is practicable, both in the winning and preparation of peat, in order to reduce the cost of production to the minimum.

In the early attempts to reduce the cost of labour, while hand digging was retained the peat as cut was shovelled into a mechanical elevator and conveyed to the hopper of the pulping mill, as illustrated in Fig. 18. Although the cost of labour was to some extent reduced, this method of feeding the elevator was found to be too expensive, and while it is still employed in some European countries, on some of the more important deposits it has been superseded by the dredger excavator, of a somewhat similar type to that used in Germany for the excavation of brown coal.

In Fig. 17 is shown a combined peat dredger excavator as used in conjunction with macerating and spreading plant, designed by the well-known peat machinery manufacturers, Aktiebolaget Abjörn Andersson, of Svedala, Sweden. The machine is shown in operation on a Swedish bog.

Both in Sweden and in Germany, as also in Canada, considerable attention has been devoted to the design of apparatus, not only for the economic winning of peat, but also for reducing the cost of labour in spreading after pulping.

Some fifty years since it was recognised that by macerating or pulping and mixing the peat it was possible to produce a much more homogeneous, dense and tough fuel. For this purpose many machines have been devised, but the type

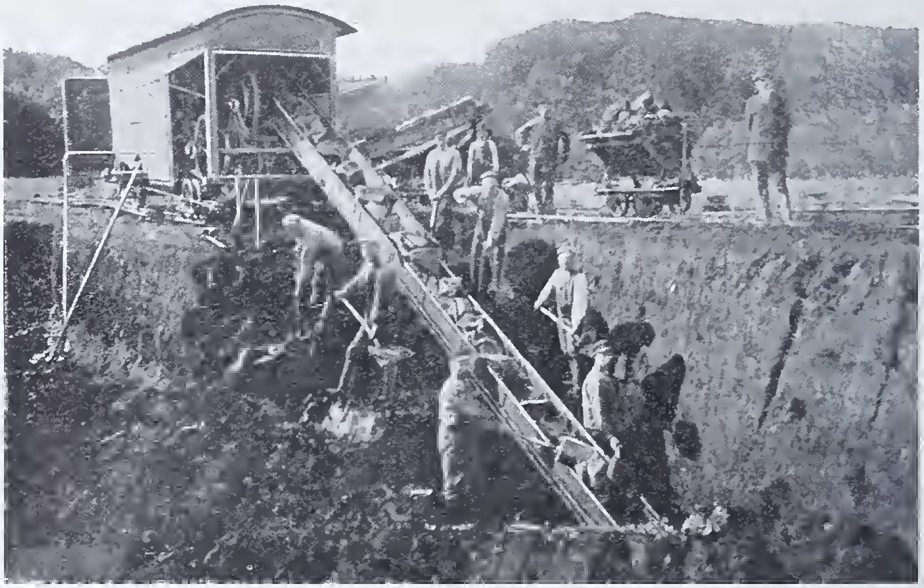


Fig. 18.—Abjörn Andersson's Mechanical Peat Elevator (Hand Fed).

of machine which is probably most extensively used is a pulping mill fed through a hopper, beneath which circular knives rotate against knives in fixed positions, and a spiral or screw conveyor which forces the peat forward to the outlet.

The whole of the working parts are enclosed in a heavy cast-iron casing. The pulping mill is power driven and very thoroughly pulps and mixes the peat. Small roots and fibrous material are broken down or cut small and mixed with the pulped peat.

The well-known Anrep macerator, as made by Aktiebolaget Abjörn Andersson, of Svedala, is illustrated in Figs. 19 and 20.

When the pulped peat is forced through the discharging mouth of the mill it is cut off in convenient lengths, usually on boards, and is then ready for transportation, spreading and air-drying.

At this stage the use of inexpensive and expeditious means for handling and

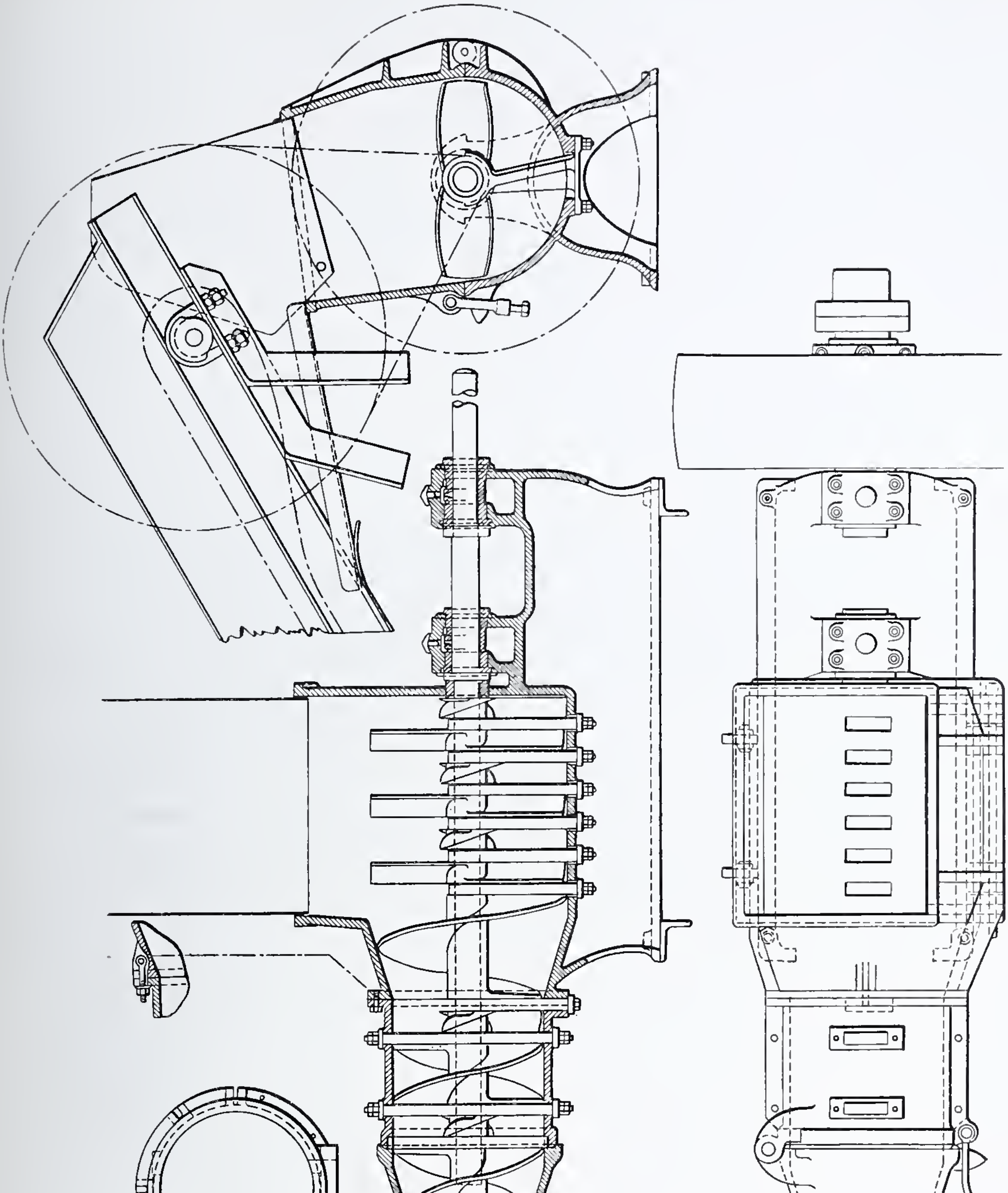


Fig. 19.—Anrep's Peat Macerator.

transportation is of much importance. For this purpose small tipping trucks on a portable track have been used, as also the telpher system.

For the spreading of the peat on the drying ground the Jakobson field press has been much used. This apparatus comprises a framework of wood, carrying two rollers, one at each end. In the centre, and between the two rollers, a hopper or container is provided for carrying the pulped peat. The roller at the front of the press is used for levelling the ground, while the rear roller, which may be adjusted vertically, is used to regulate the thickness of the peat discharged. As the peat leaves the press at the rear roller it is cut into long strips by means of a series of fixed knives; these long strips are subsequently cross cut by hand labour.

Among the most ingenious peat spreading machines devised is that designed by Mr Ernest V. Moore, and which has given much satisfaction in Canada. This

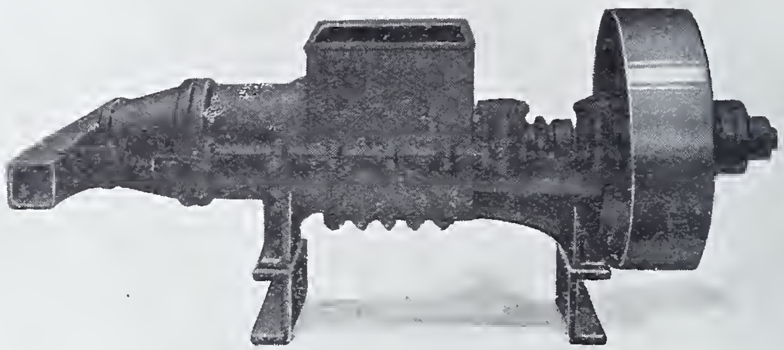


Fig. 20.—Anrep's Peat Macerator.

spreader, which embodies some novel features, was designed for carrying on a special type of caterpillar tractor electrically driven by a trolley system, at the rate of about 7 ft. per minute.

From the peat container on the spreader the peat is evenly distributed by means of a screw conveyor, being discharged from the container at ground level through a series of parallel spouts, each spout or outlet being provided with a separate screw feed. By means of a controlling device the peat may be discharged within considerable limits at any speed desired.

Unlike the Jakobson field press, the Moore spreader automatically cross-cuts the peat, thus eliminating subsequent labour in cutting. In Fig. 21 is shown a conveyor (Personn's patent), manufactured by Aktiebolaget Abjörn Anderson, of Svedala. The macerated peat upon leaving the machine is delivered on to boards or pallets which are carried on a roller table, which is provided with an automatic cutting device. A section of this table is so supported that when engaged by a loaded board it is automatically lowered, the board with its contents being transferred to the endless wire rope conveyor and carried across the drying field.

The cables are supported at a convenient height on light angle iron trestles having rollers to carry the cables. The trestles are usually placed from 10 to 12 yards apart, and are provided with metal sledge bases for easy transportation. The driving mechanism for the conveyor is mounted on the machine truck carrying the macerator and engine or motor.

This very simple and inexpensive type of conveyor may be satisfactorily operated in any length up to 200 yards. The boards carrying the peat have to be tipped by hand, but when placed on the return conveyor are carried back on the machine and automatically removed.

It has been estimated that the total annual consumption of peat in European

Fig. 21.—Personn's Peat Conveyor.

countries is from 15 to 20 million tons per annum. The peat deposits of the world, in so far as they have been estimated and surveyed, are as follows :—

Country.	Area in sq. miles.
Great Britain	9,400
Ireland [1]	4,700
United States [2]	11,200
Canada	37,000
Sweden	19,200
Norway	2,900
Denmark	400
Germany	9,900
Austria	1,500
Russia	65,000
Finland	38,000

[1] Estimated quantity = 5,000,000,000 tons.

[2] United States Geological Survey, 1918-20. Calculated upon an air-dried basis, almost 14 billion tons.

Great Britain.—Probably the most important of the peat deposits in England which is still being actively developed is that owned by the Eclipse Peat Company at Ashcott, Somerset, in the historic Glastonbury district.

By the courtesy of Mr P. J. Slee, one of the proprietors, the author is able to include the illustrations, Figs. 22 to 28, showing in the various stages the winning and air-drying of peat at this works. Eclipse peat for domestic fuel purposes is all obtained at a minimum depth of about 6 ft., a typical analysis being as follows :—

Ash	3·03 per cent.
Sulphur	very slight trace
Phosphorus	none
Carbon	56·0 per cent.
Hydrogen	5·8 ,,
Oxygen	37·1 ,,
Nitrogen	1·1 ,,
Tar	16·0 ,,

Some recent examples have shown an ash content of rather less than 2 per cent. For several years past much experimental work has been done in distillation and bye-product recovery, as also in mechanical dehydration. So successful have these experiments in dehydration been that the Company now contemplate installing a larger plant for this purpose.

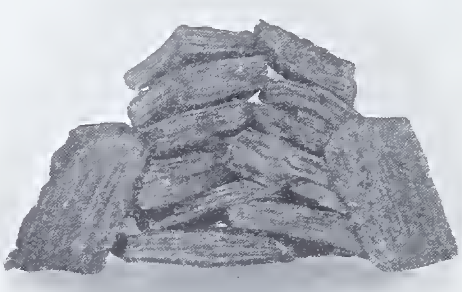


Fig. 22.—Air-dried Ashcott Peat.

In the production of alcohol from peat very encouraging results have been obtained. One ton of raw peat, having a moisture content of from 80 to 90 per cent., yielded 6 gallons of high grade alcohol suitable for internal combustion engines. The peat used was a light fibrous peat from the top layers of the bog.

Ireland.—It has been estimated that peat is used for domestic purposes in Ireland by about $1\frac{1}{2}$ million people, and that the annual consumption is approximately 7 million tons. Comparatively little peat is used for industrial purposes, but the following two cases are interesting examples :—

At the Marconi Company's Wireless Station at Clifden, from 5000 to 6000 tons per annum of air-dried peat is used for steam generation. At Mr Hamilton Robb's Linen Factory, Portadown, peat is used in two Crossley producers, each 200 B.H.P., supplying three Stockport gas engines, two being rated at 120 B.H.P. each, and one at 150 B.H.P. The usual output is said to be about 250 B.H.P. Under test the consumption is reported to have been from 2·5 to 3·16 lbs. of 25 per cent. moisture peat per B.H.P. hour. The latter is equivalent to 4·24 lbs. per kw. hour,

Fig. 23.

Fig. 24.

Fig. 25.

Fig. 26.

Fig. 27.

Fig. 28.

The Winning and Air-drying of Peat at the Works of The Eclipse Peat Company, Ashcott, Somerset.

and assuming a value of 10s. per ton for the peat, would represent a cost of ·22 pence per kw. hour.

In addition to the peat used in the producers, some 2500 tons per annum is used for the firing of steam boilers, to provide steam for heating purposes, etc. By the courtesy of Messrs Crossley Bros., Ltd., the author has been enabled to reproduce an illustration of the producers at Mr Hamilton Robb's Factory (see Fig. 29).

During the past few years much attention has been directed to the development

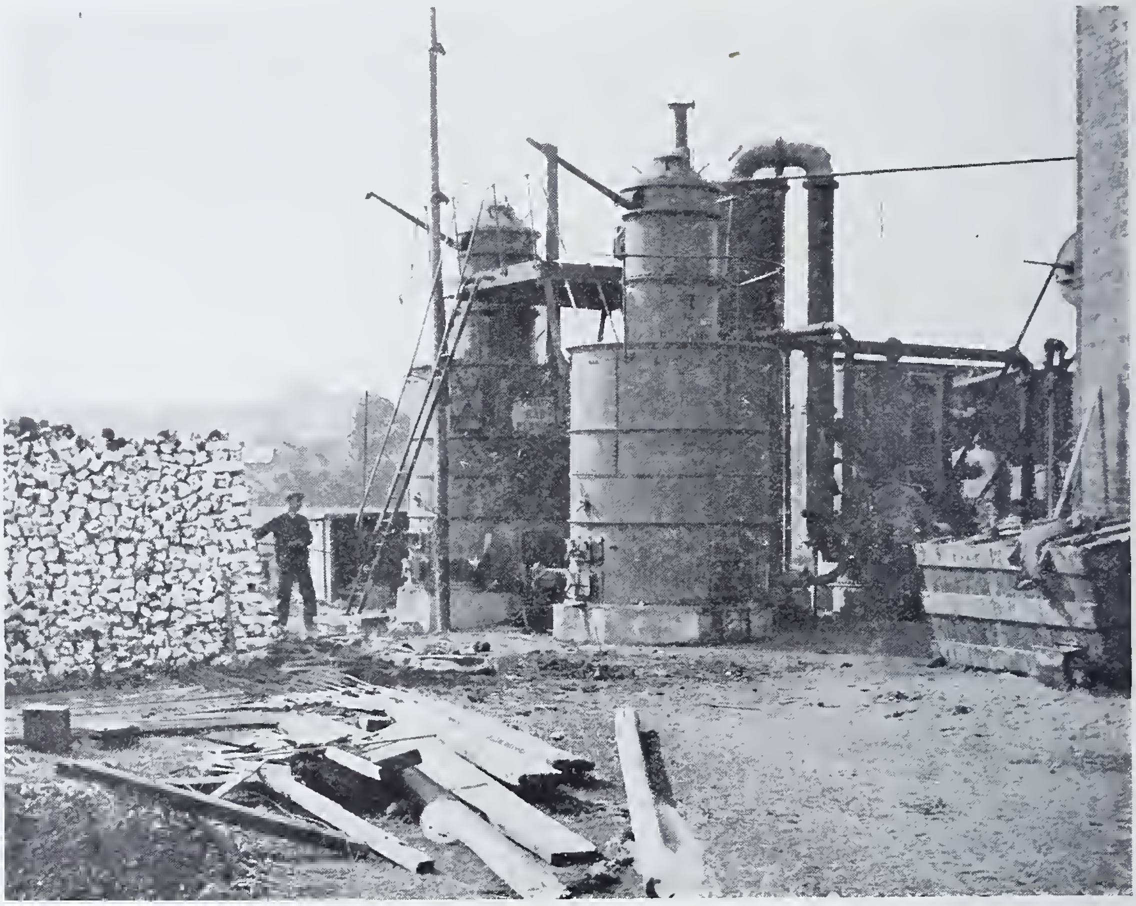


Fig. 29.—Crossley Producers gasifying Peat at Mr Hamilton Robb's Linen Factory, Portadown.

of the peat resources of Ireland, and much valuable information, as also definite recommendations, will be found in an excellent brochure, issued by H.M. Fuel Research Board (Department of Scientific and Industrial Research) in 1921, entitled " The Winning, Preparation, and Use of Peat in Ireland; Reports and other Documents."

According to this Report (p. 75), a Dolberg peat macerating machine and also an Abjörn Anderson peat machine with accessories have been installed at Turraun, and 100 tons of air-dried peat were sent to H.M. Fuel Research Station at East

Greenwich, "for experimental work on its use, directly as a fuel, and indirectly as a source of gas, oils and char."

In Technical Paper No. 4 [1] of H.M. Fuel Research Board, 1921, very complete and interesting details are given of carbonisation tests of macerated Irish peat from Turraun.

The peat as received at the Fuel Research Station at East Greenwich was in the form of "hard blocks about 10 in. long, with a cross section of about 2 in. square. Their density was rather under 1, or about twice that of the ordinary hand-cut sods made on the bog. These blocks could be sawn and cut like hard wood, and had stood transport with very little breaking up into "smalls," thereby contrasting very favourably with ordinary hand-cut sods, which break down seriously in transport by road or rail.

"On arrival the water content of the blocks was about 25 per cent., but by the date of the experiments described this had been reduced on storage under cover to 17 per cent."

Commenting upon the experiments, it is stated in the Report :—

"Not only do these peat blocks lend themselves admirably after suitable treatment to carbonisation in vertical retorts at temperatures between 750° C. and 850° C., but also in steel retorts at 550° C. and 600° C., and the resultant charcoal is an ideal fuel for suction gas producers."

Canada.—With the same thoroughness which has characterised the investigation of fuel problems generally, the Canadian Government Department of Mines have closely studied peat and its development. In his work,[2] which has already been referred to, Mr B. F. Haanel, B.Sc., Chief of Fuels and Fuel Testing Division, Department of Mines, Ottawa, refers to the system of peat transportation and spreading designed by Mr Ernest V. Moore, and in operation at Alfred Peat Bog, Ontario, and also under the heading of "Canadian Practice," pages 26 to 30, describes the work done on a commercial scale at the Farnham, Quebec, and Alfred, Ontario, bogs.

Commenting upon the operations throughout two seasons, Mr Haanel says :—

"During two seasons the Mines Branch manufactured about 3000 short tons of 25 per cent. moisture air-dried machine peat fuel. The method employed was that invented by Anrep, the system which is so extensively used in Russia and Sweden. The plant was not equipped with a mechanical excavator, and its capacity was small—only about 30 tons per day—hence the overhead charges, amortisation, interest on investment, etc., were high. The improved 'Anrep' system as employed at this plant is described elsewhere; it is only necessary, therefore, to add a few remarks regarding the cost of manufacture.

"The result of two seasons' manufacturing operations at Alfred, under unfavourable conditions, indicate that with efficient management peat fuel can be manufactured at a cost of \$1·75 on the field. This cost includes all expenses, such

[1] Technical Paper No. 4, H.M. Fuel Research Board (Department of Scientific and Industrial Research), 1921, "The Carbonisation of Peat in Vertical Retorts."

[2] "Peat, Lignite, and Coal," by B. F. Haanel, B.Sc., Department of Mines, Ottawa, 1914.

as interest on investment, amortisation, repairs, etc. It is, moreover, the opinion of the Swedish peat engineer, who conducted the last seasons' operations, that a period of 110 working days can be counted upon as a fair period during which manufacturing operations may be conducted. The total production during this time would be 3300 short tons, and this output will be used as a basis in calculating the cost per ton."

In "Peat as a Source of Fuel,"[1] Mr Eugene Haanel, Director of the Canadian Government Mines Branch, Ottawa, gives very concise details of the peat resources of Canada, from which it would appear that the total area of the Dominion overlain by peat bogs is estimated to be 37,000 square miles.

In this address to the Commission of Conservation, Mr Haanel thus referred to the utilisation of peat :—

"The extensive and varied field for the utilisation of peat must be apparent to all who have closely studied this question, and the urgent need for an intensive development of the Canadian peat resources should be brought forcibly before men actively engaged in the building up of the great commercial enterprises and industries of this country."

United States.—Notwithstanding the abundant coal resources of the United States, a comprehensive investigation of the peat resources was carried out in 1918-20 by the United States Geological Survey. Although a considerable amount of experimental work has been done, there has been no incentive or necessity to develop the peat resources. Within the past few years experiments have been made at Minneapolis, Minn., with pulverised peat for the firing of steam boilers, but no data is yet available.

Russia.—Some years since the annual output of peat in Russia was in excess of that of any other country in the world. The last available figures, for the year 1914, showed a very considerable reduction, the output being about $2\frac{1}{2}$ million tons only.

Bogerodzk Power Station, some 43 miles from Moscow, having a plant capacity of 15,000 kw. (3·5000 kw. Zoelly Turbines), supplied with steam from air-dried peat burned under water tube boilers—which Power Station was put into operation in 1914—was the largest generating station in the world operated on peat. The power was supplied to local industrial works, surplus power being transmitted to Moscow.

Germany.—While there would appear to have been a decline in recent years, the use of peat has been considerably developed in Germany. The most important power plant using peat for steam generation is at Weismoor Ostfriesland.

The original installation[2] comprised a steam plant of 200 H.P. only, which was used for the cultivation of the bog, ditching, stripping, and ploughing. The utilisation of peat for power production was apparently not originally intended.

In 1908 it was decided to considerably extend the power plant. The plant

[1] "Peat as a Source of Fuel," by Eugene Haanel, Director, Mines Branch, Ottawa. Reprinted from the Ninth Annual Report of the Commission of Conservation, Canada, 1918.

[2] "Das Kraftwerk im Weismoor Ostfriesland," by J. Teichmüller, Karlsruhe, Germany.

then installed comprised four water tube boilers each having 3228 sq. ft. of heating surface, superheaters each having 1076 sq. ft. of heating surface, and grates of 86 sq. ft. each; the steam pressure was 176 lbs. The generating plant provided comprised three Turbo sets, each of 1250 kw. capacity. As the result of exhaustive experiments in the burning of peat the furnaces were altered, step grate furnaces inclined at 36° to the horizontal were installed, and the grates were also divided to permit of alternate feeding.

An evaporative test carried out in 1910 showed an overall thermal efficiency of 73·5 per cent., and an evaporation of 3·01 kg. per kg. of peat, burned (5·4 lbs. per lb.). The moisture content of the peat as fired was not stated.

The present capacity of the Weismoor Generating Station is about 18,000 kw. The annual consumption of peat is approximately 60,000 tons. Eight boilers are fired with peat and four boilers are fired with coal, the annual coal consumption being about 30,000 tons.

Considerable quantities of peat have been used in Germany for steam generation and for other industrial purposes. In order to use the peat to the best advantage, much experimental work has been done with a view to designing grates and furnaces suitable for various grades of peat.

The most efficient furnaces evolved for steam boilers would appear to be those of the step grate type, the grate usually being inclined at about 36° to the horizontal, and so arranged that two or more furnaces may be fixed parallel, these being fed alternately from hoppers fixed above.

Another type of furnace to which Hausding refers as having given good results is similar to a type which has been extensively used in Great Britain for the past twenty-five years for the burning of towns' refuse, this being a furnace having two or more separate ashpits with a continuous grate and common furnace chamber.

Generally it would appear that ordinary flat grates are useless, and that, having in mind the various grades of peat used and their variation in density, it is necessary to devote close attention to the requirements of particular grades of peat, both in regard to the most suitable grate area and furnace dimensions.

The various peat furnaces which are used in Germany for steam generation and for other industrial purposes are fully discussed in a very useful work by Francis Rauls.[1]

Italy.—For some few years past a large peat producer plant has been in operation at Orentano, Tuscany. This plant has an annual consumption of about 30,000 metric tons, and is operated by L'Utillizziazione dei Combustibile Italiani E. L'Impianto de Orentano. The peat, which has an initial moisture content of about 77 per cent., is dried down to about 30 per cent. moisture, and is gasified in Mond producers.

Sweden.—In Sweden peat has been regarded as an important fuel, and much research and experimental work has been done with a view to its efficient utilisation for steam generation, etc.

Peat development has for many years past been subsidised by the Swedish

[1] "Handbuch der Trocken und Brenn-ofen," by Francis Rauls, Cologne, 1915.

Government. Facilities have also been provided for the training of peat engineers. The reputation of Swedish trained peat engineers is such that for all important development work their services are regarded as essential.

In 1916 the Swedish Boiler Control carried out an extensive series of evaporative tests for a Royal Commission at the Electricity Works of Höganäs Billesholms-A.B. with Pluto mechanical stokers, fired with peat. These mechanical stokers are described and illustrated elsewhere.

These tests were made with a water tube boiler having 208 sq. metres of heating surface, and a superheater having 36 sq. metres of heating surface. The Pluto mechanical stoker had a total grate area of 10·2 sq. metres, the effective grate area being 8·7 sq. metres, and was originally installed for burning coal.

The peat used was machine peat from the Emmaljounga moor, and was dug in 1915. Before firing it was broken up into 3-in. cubes, the analysis being as follows :—

Volatile matter	=52·3 per cent.
Ash	= 3·7 ,,
Moisture	=24·6 ,,
Lower heating value	=3600 calories.

The primary purpose of the tests was to determine (*a*) the efficiency of the ignition, (*b*) the boiler evaporation, and (*c*) the thermal efficiency of the boiler and superheater.

During the first test, although the grate was working at its highest speed this was found to be insufficient, and it was impossible to feed a sufficient quantity of peat. It was, however, shown that the peat was quickly ignited and the rate of combustion was high. The evaporation was at the rate of 16·2 kg. per sq. metre of heating surface per hour.

For the second test the speed of the stoker was increased, with a proportionate increase in the rate of evaporation, which was 25·5 kg. per sq. metre of heating surface, or 174 kg. per sq. metre of grate area. The average CO_2 content of the gases was 15·8 per cent., and the thermal efficiency 70·2 per cent.

With a view to determining if the evaporative output could be further increased a third test was made, with a higher grate speed and a constant fire thickness of 310 mm., with the result that the rate of combustion was increased to 211 kg. per sq. metre of grate surface per hour, the CO_2 content in the gases being 16·2 per cent. and the thermal efficiency 70 per cent.

Throughout the tests the thermal efficiency varied from 70 per cent. to 73·4 per cent., with a high percentage of CO_2 in the gases. The performance of the Pluto stoker is particularly noteworthy having in mind that the same arrangement of stoker and brickwork was suitable for burning coal, the only alteration made being in the speed of the grate movement.

As already observed, the future development of peat on any extensive scale will depend mainly upon the provision of economic means for the reduction of the moisture content. In a reasonably dry condition it is a valuable fuel, the main disadvantage of which is its bulk.

In the past, whenever the cost of coal has been considerably increased, and also as the result of periodical extreme shortage, there has been a spasmodic revival of interest in the development and use of peat. There are, however, signs that the present revival of interest in peat production will be of a much more permanent nature, and that in some of the coalless countries, where peat is available, this fuel will be used to a greater extent than hitherto.

An extended period of coal shortage and high prices has had the effect of stimulating activity in the development of such natural fuels as are available in some countries, just in the same way that in many other countries a great impetus has been given to the development of hydro-electric power.

CHAPTER V

COKE BREEZE

Coke breeze or screenings from the large coke, when withdrawn from retorts or coke ovens, is now very extensively used for steam generation, and also for other purposes.

Until within recent years it has been generally classified as a low grade or waste fuel, and of but doubtful value, but as the result of its very extensive and successful use for steam generation in gas-works, it was gradually adopted in industrial works for the same purpose, where the conditions were suitable, with equally satisfactory results. Twenty years ago large quantities of surplus coke breeze were constantly available at gas-works in all parts of Great Britain, the price varying from 1s. to 5s. per ton, whereas at the present time the demand is so considerable that the price at some works approximates to that of slack coal of average quality, and generally speaking all breeze made is readily sold.

As the result of screening and grading coke breeze for sale for particular purposes, to a large extent that which was known as rough or unscreened breeze, varying in size from $1\frac{1}{4}$-in. cube to dust, is no longer obtainable.

Rough coke breeze was an excellent fuel for steam generation, its calorific value and ash content being often equivalent to that of a bituminous slack sold at from two to three times its cost per ton.

The screening and sizing or grading of coke breeze is now common practice, with the result that the term coke breeze is very indefinite. In the case of the smaller gas-works, where little or no screening is done, it may mean rough or unscreened breeze ; in other works it may mean fuel which has passed a $\frac{3}{8}$-inch or $\frac{1}{4}$-in. mesh screen, containing a very considerable proportion of dust.

Not only does coke breeze vary considerably in size, but its composition varies widely according to the quality of the coal carbonised and the type of carbonising plant used, as will be observed from the following analyses in Table No. 22.

TABLE No. 22

Proximate Analyses of Coke Breeze

Gas Works. District.	Fixed carbon.	Volatile matter.	Ash.	Moisture.	Calorific value B.T.U.'s.
Nottingham . .	63·23	4·50	14·17	18·10	9.260
Northumberland . .	64·04	5·04	17·81	13·11	9,898
Sussex . . .	56·17	4·65	23·65	15·33	8,884
Cheshire . . .	66·97	11·41	17·87	3·75	11,365
Scotland . . .	58·36	3·62	15·23	22·79	8,611
South Wales . .	69·77	7·45	20·06	2·72	11,297

TABLE No. 22—*continued*

Coke Ovens. District.	Fixed carbon.	Volatile matter.	Ash.	Moisture.	Calorific value B.T.U.'s.
Derbyshire	48·96	4·28	15·28	11·48	10,177
South Wales	63·29	5·79	16·10	14·82	9,529
North Staffordshire	61·64	9·42	15·61	10·30	10,119
South Yorkshire	65·73	7·85	15·01	10·81	10,260
West Yorkshire	76·90	2·99	18·62	1·49	11,191

Recent analyses of gas-works coke breeze from Doncaster, Gosport, and Swansea gave the following results :—

	Doncaster.		*Gosport.*		*Swansea.*	
Date of Analysis.	July 1922.		October 1922.		June 1923.	
	As received.	As dried.	As received.	As dried.	As received.	As dried.
Volatile matter	6·34	6·52	7·01	7·72	8·94	10·96
Coke	90·85	93·48	83·79	92·28	72·63	89·04
Ash	15·86	16·32	24·74	27·25	17·77	21·78
Fixed carbon	74·99	77·16	59·05	65·03	54·86	67·26
Free moisture	..	..	6·36	..	15·21	..
Hygroscopic moisture	2·81	..	2·84	..	3·22	..
Calorific value B.T.U.'s	12,102	12,765	9572	10,905	9203	11,630
Carbon equivalent B.T.U.'s	..	12,175	..	10,585	..	11,381
Evaporative power (lbs. of water per lb. of fuel from and at 212° F.)	12·53	13·21	9·91	11·28	9·52	12·04

As a general rule the calorific value of coke breeze varies from 8500 to 10,500 B.T.U.'s per lb., the ash and moisture content usually varying from 10 per cent. to 15 per cent.

Owing to the method adopted of quenching the hot coke as withdrawn from the retorts, coke breeze like coke absorbs a considerable quantity of moisture, which as the result of the physical structure of the fuel is mechanically held. The percentage of moisture thus held is one of the most serious objections to the use of coke breeze as a fuel, and it is very desirable that improved methods of quenching or cooling should be introduced. Many steam users strongly object to the purchase of from 180 to 336 lbs. of water with every ton of coke breeze ; actually this has to be paid for twice, because not only does it represent a definite loss of weight in fuel with every ton purchased, but extra fuel has to be burned to drive off the moisture.

When used for the firing of steam boilers small coke breeze makes a close lying and compact fire, the bed of fuel presenting considerable resistance to the flow of air, which preferably should be uniformly distributed at a pressure of from $\frac{1}{2}$ in. to $\frac{5}{8}$ in. W.G.

The author is well aware that pressures in excess of this are now much advocated, and that rates of combustion of from 30 to 40 lbs. of fuel per sq. foot of grate per hour are claimed, but while such results are practicable, they involve the carrying forward of excessive quantities of dust and partially consumed fuel into the flues.

The best authorities are agreed that a rate of combustion of 25 lbs. per sq. ft. of grate per hour, which has been conclusively established as the most efficient rate of combustion for coal, should be the maximum rate of combustion for coke breeze.

If this average rate of combustion, which may be termed the permissible rate, is exceeded, trouble is invariably experienced as the result of "lifting," and carrying over, of excessive quantities of unburnt and partially burnt fuel and dust into the flues, causing rapid choking, reduced heating surface, restricted areas, and back draught, with a consequent decreasing efficiency. Further, it has been found that slow combustion sometimes proceeds in the flame bed of the boiler for many weeks, involving a serious risk of overheating and bulging or distortion of the boiler shell plates, while also presenting very dangerous conditions for flue cleaning.

High rates of combustion have been and still are employed, in order to show that with a particular type of furnace an internally fired boiler with a limited grate area will give with coke breeze a rated evaporation equivalent to that obtainable with the best steam coal.

In seeking to prove this there is no regard whatever for the relative thermal efficiencies obtained, which under such conditions with coke breeze may be as low as from 55 per cent. to 60 per cent., as against 65 to 70 per cent. obtained at the most efficient rate of combustion.

Referring to the utilisation of coke breeze for the generation of steam, in a paper [1] entitled "The Production of Steam from Low Grade Fuel," Mr P. Parrish, A.I.C., expressed the following opinion :—

"A Lancashire boiler which is capable of evaporating say 600 gallons of water per hour with best steam coal is incapable of being worked with coke breeze at a maximum thermal efficiency above a productive capacity of 400 gallons per hour."

As the result of exhaustive experiments with coke breeze for the generation of steam Mr Parrish was able to show that the most efficient grate area for a Lancashire boiler 8 ft. in diameter was 26 sq. ft., whereas the standard grate area usually provided and strongly advocated would be 38 sq. ft., *i.e.* 6 ft. × 3 ft. 2 in. × 2 ft. Further, that the thickness of the fires should be from 6 in. to 8 in. Thinner fires are unsuitable owing to the tendency to develop "blow holes."

The grate area and the thickness of the fuel bed are both points of considerable importance in the efficient combustion of coke breeze. Although there has been a tendency to recommend a fire thickness of from 1 ft. 6 in. to 2 ft., those who have had experience in the burning of close-lying fuels, often having a high ash and moisture content, will be well aware that the conditions presented for combustion, and the effective cleaning of the fire, cannot be regarded as satisfactory.

Mr Parrish found that by reducing the length of the grate to the extent of

[1] "The Production of Steam from Low Grade Fuel," by P. Parrish, A.I.C., *Journal of the Society of Chemical Industry*, July 31, 1919.

about 20 per cent., that the temperature of the exit gases was reduced from 310° C. to 240° C., that a lesser quantity of fuel was consumed, that the capacity or evaporative output of the boiler was unimpaired, and that the chimney draught was not adversely affected.

The following results with coke breeze were obtained over a period of three months at Phœnix Wharf, London, and are included in the valuable paper by Mr Parrish, which has already been referred to :—

TABLE No. 23

Coke breeze burned . . .	412·3 tons
Analysis	
Moisture	10·30 per cent.
Ash	29·31 ,,
Carbon (by difference) . . .	60·39 ,,
Calorific value (calculated) . .	8800 B.T.U.'s. per lb.
Volume of softened water . .	=480,010 gals.
Less water blown down . . .	=17,030 ,,
Volume of water evaporated . .	=462,980 ,,
Volume of water evaporated per lb. of fuel	=5·0 lbs.
Temperature of feed water . .	=55·5° C.=130° F.
Average steam pressure . . .	=99 lbs. absolute.
Thermal efficiency . . .	=61·5 per cent.
Loss due to unburnt clinker	
Ash in fuel	=29·31 per cent.
True ash in dry clinker . . .	=87·50 ,,
Clinker per lb. of fuel . . .	=0·335 lb.
Carbon in dry clinker . . .	=12·5 per cent.
Loss of carbon in 0·335 lb. clinker	=0·049 lb.
Loss of carbon based on 0·6039 lb. carbon	=20·4 per cent.

The boiler used for this test was of the Lancashire type, 27 ft. long×8 ft. in diameter. The average rate of combustion would appear to have been about 30 lbs. per sq. ft. of grate per hour.

While the evaporative results as given above over a period of three months with a dirty fuel are exceedingly good, the following average results of 631 steam trials of coke breeze by Mr T. W. Andrews present in very compact form conclusive and valuable evidence as to the fuel value of coke breeze.

In comparing the fuel efficiency with that shown in the above figures it is interesting to note not only the average calorific value of the coke breeze as fired, but also the comparative rates of combustion, the rate of evaporation and thermal efficiency being practically the same in each case.

The grate area, which is given as 44·2 sq. ft., indicates that grates 7 ft. long were used. This length of grate is excessive for hand firing, and is very difficult to keep evenly covered. The only apparent advantage realised is in reducing the rate of combustion. The average rate of evaporation shown agrees substantially with the conclusions of Mr Parrish, and is considerably below the rated evaporation of a Lancashire boiler of the size in question. Average result of 631 steam trials.[1]

TABLE No. 24

Particulars of Boilers—	
Type	Lancashire.
Size	28 ft. long × 8 ft. diameter.
Heating surface	1,180 sq. ft.
Grate area	44·2 ,,
Draught	Forced.
Conditions of Evaporation—	
Temperature of feed	62° Fahr.
Steam pressure (absolute)	91·5 lbs.
Heat supplied to each lb. of water	1,149·8 B.T.U.
Factor for equivalent evaporation	1·19
Quantity of Fuel Burned—	
Total weight in lbs.	6,750 lbs.
Weight per hour in lbs.	844 ,,
Weight burned per sq. ft. of grate per hour	19·1 ,,
Calorific value per lb. as fired	9,650 B.T.U.
Quantity of Water Evaporated (actual)—	
Total quantity evaporated in lbs.	34,814 lbs.
Quantity evaporated per hour in lbs.	4,352 ,,
Quantity evaporated per sq. ft. of heating surface per hour in lbs.	3·69 ,,
Quantity evaporated per lb. of fuel as fired in lbs.	5·15 ,,
Equivalent Quantity of Water Evaporated—	
Total equivalent evaporation from and at 212° F. in lbs.	41,428 lbs.
Total equivalent evaporation per hour in lbs.	5,178 ,,
Total equivalent evaporation per sq. ft. of heating surface per hour in lbs.	4·39 ,,
Total equivalent evaporation per lb. of fuel as fired in lbs.	6·12 ,,
Thermal efficiency	61·3 per cent.

[1] "Fuel Economy on Gas Works Boilers," by Mr T. W. Andrews, South Metropolitan Gas Company. Paper read before London and Southern District Junior Gas Association, Dec. 15th, 1922.

Although under certain favourable conditions, and with a greatly reduced evaporative output, it is possible to use coke breeze for steam generation under natural or chimney draught alone, for its efficient utilisation the use of artificial draught is essential.

For the past thirty years hand fired furnaces of the steam jet blower type have been extensively used for the burning of coke breeze, it may in fact be said that upwards of 95 per cent of the breeze furnaces now in use are of this type.

While many fuels can be more efficiently burned with fan forced draught, *i.e.* a dry air supply, there can be no doubt that the most efficient results are obtained from coke breeze when using an air supply carrying moisture ; it is for this reason that steam jet blower furnaces are almost universally used for the burning of coke breeze.

For an installation comprising more than one boiler in constant use, there is no doubt that in the actual consumption of steam for the delivery of the air supply, fan forced draught is the more economical. There are, however, other considerations, such as simplicity, reliability, maintenance cost, and capital cost, all of which are in favour of the steam jet blower furnace. Further, with this type of furnace two outstanding advantages are secured as the result of using a moist air supply :—

(*a*) The clinker does not adhere to the grate, and may be removed with much less effort, and

(*b*) The grates have a much longer life than is the case when dry air is employed.

The essentials of an efficient hand fired breeze furnace may be briefly stated as follows :—

(1) The grate should be so designed, the air spacing so arranged, and the air supply so delivered, that the undergrate air pressure is equally distributed.

(2) The grate should preferably be suitable for use under ordinary chimney draught conditions, in order to meet light load requirements when desired without damage.

(3) The ashpit should be clear and unobstructed so as not only to be suitable for working under chimney draught, but also to avoid possible trouble due to condensation, corrosion, and wastage of the plates.

(4) The steam jet blowers should be designed to give a definite air delivery under given conditions.

(5) Steam jet blowers should be noiseless in operation. The noise from ordinary open undergrate blowers is most objectionable and quite unnecessary.

(6) Having in mind the nature of the work which has to be done, the whole furnace should be of the most substantial and durable construction.

Generally speaking, steam jet blower furnaces may be classified in three distinct groups : (*a*) Undergrate blower furnaces, with which system the blowers are arranged in the ashpits immediately beneath and parallel with the grates ; (*b*) pressure bar furnaces using segmental channel or other hollow firebars, with a separate steam jet for the supply to each firebar or air channel ; (*c*) external blower or noiseless furnaces, with which system the blowers are arranged vertically and

externally, the ashpit being free from any obstruction. In Figs. 30, 31, and 32 are shown the three types of steam jet blower furnaces above referred to.

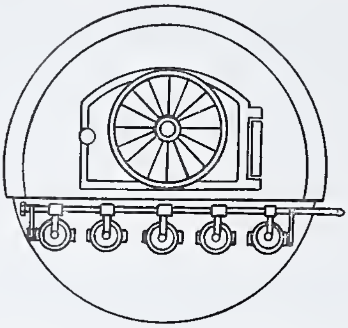


Fig. 30.—Type of Steam Jet Blower Forced Draught Furnace, as used for Burning Coke Breeze.

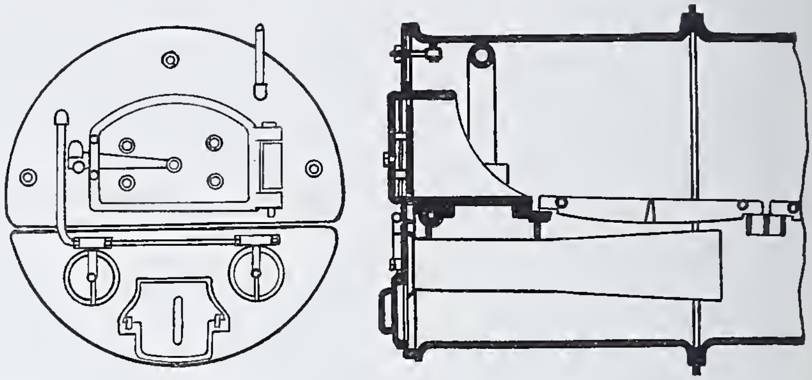


Fig. 31.—Type of Steam Jet Blower Forced Draught Furnace, as used for Burning Coke Breeze.

In so far as the actual working efficiency is concerned, despite all claims to the contrary, there is but little if any material difference between the three classes.

The fuel can be burned at equal rates with an equivalent efficiency with either class. The outstanding differences are found in the method of air delivery, and in the type and arrangement of the grate; apart from these features the choice lies

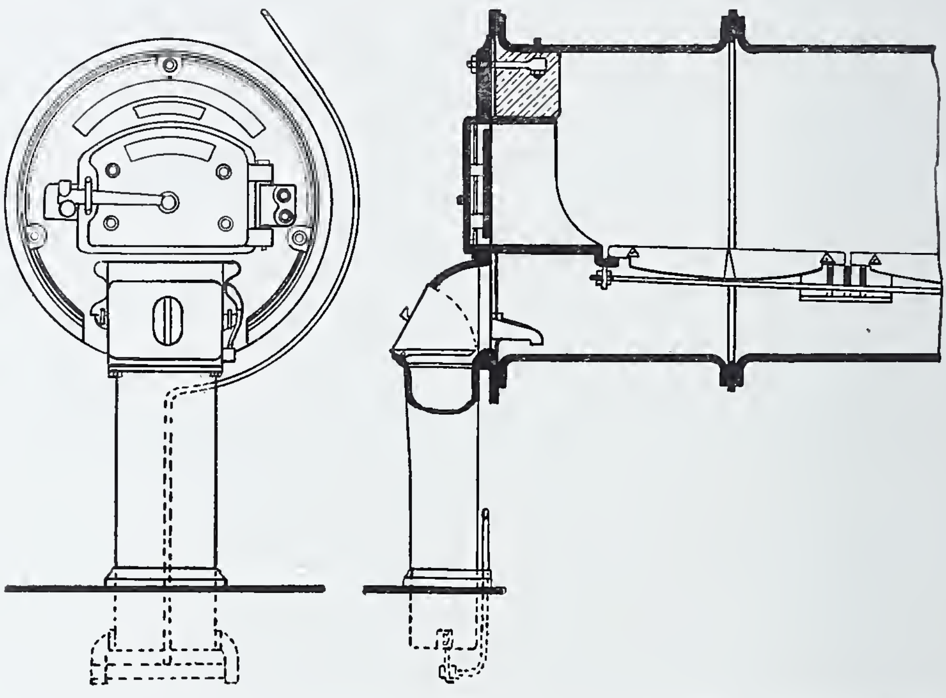


Fig. 32.—Type of Noiseless Steam Jet Blower Forced Draught Furnace, as used for the Burning of Coke Breeze.

between a single air chamber or a number, and the constant noise, which is a feature of all open undergrate blowers, or, on the other hand, noiseless operation.

As already observed with Lancashire and Cornish, or internally fired boilers, which are mainly used both in gas works and in other industries utilising coke

breeze, the evaporative output is reduced as the result of a necessarily restricted grate area, and a limited rate of combustion.

With the adoption of larger steam generating units in the form of water tube boilers, equipped with mechanical stokers suitable for burning coke breeze, it has been shown that with this fuel when used with grates of ample area it is possible to obtain the full rated evaporative output from a boiler, with a rate of combustion varying from 25 to 28 lbs. of fuel per sq. ft. of grate per hour.

The following figures of evaporative tests with travelling grate stokers of the Underfeed Stoker Company's make are of much interest, having in mind the low calorific value of the breeze and the percentages of ash and moisture :—

TABLE No. 25

Evaporative Tests with Underfeed Travelling Grate Stokers burning Coke Breeze

	Glasgow Corporation Gas Department.	Marylebone Electricity Works, London.	Bristol Corporation Electricity Works.	Priestman Colliery Limited.
Fuel.	Gas Coke Breeze.	Coke Breeze.	Coke Breeze.	Coke Oven Breeze.
Analysis of Fuel: Ash %	13·4	. .	25·03	23·4
Analysis of Fuel: Volatile %	6·97	3·83	6·82	. .
Analysis of Fuel: Moisture %	18·41	17·6	13·68	16·65
B.T.U. as fired	8832	8126	8927	8700
Duration of test, hours	6	4	6 full load	6
Steam pressure	138	199	200	149
Draught gauge at damper inches W.G.	1·5	0·32	0·3	. .
Absolute steam pressure	. .	. .	214·7	208·7
Air pressure in wind box	. .	. .	0·6	. .
Gases leaving boiler Fahr.	445°	521°	552°	520°
Feed water entering boiler	162·6°	90°	240°	171·2°
Steam temperature Fahr.	. .	572°	538°	525·4°
Superheat deg. Fahr.	100°	184·7°	150°	140·1°
Total fuel consumed, lbs.	. .	14,952	19,264	7504
Total refuse dry, lbs.	. .	. .	4956	1764
Total refuse dry, percentage by analysis	. .	. .	25·72 %	23·4 %
Fuel as fired per hour lbs.	2433	3738	3211	1250
Fuel as fired per square foot of grate. lbs.	25·2	28·5	28·16	27·7
CO_2 in gases leaving boiler	12·5 %	14 %	13 %	9·43 %
Total weight of water used, lbs.	. .	71,200	116,000	38,097
Factor of evaporation boiler including superheater	1·156	1·287	1·11	1·177
Total, from and at 212 deg. Fahr. including superheater, lbs.	. .	. .	128,760	. .
Amount used, lbs.	. .	17,800	19,333	6349·5
Evaporation from and at 212 deg. Fahr. including superheater, lbs.	17,012	. .	21,459	. .
Evaporation per pound actual, lbs.	6·04	4·76	6·02	5·077
Equivalent evaporation from and at 212 deg. Fahr. including superheater, lbs.	7·00	6·12	6·68	5·97
Evaporation from and at 212 deg. Fahr. per square foot of heating surface, lbs.	4·16	. .	3·97	. .
Efficiency	76·7 %	72·7 %	72·36 %	66·3 %

The following figures of an evaporative test of twenty-four hours' duration at Temple Gas Works, Glasgow Corporation Gas Department, with a Babcock & Wilcox boiler and chain grate stoker, show excellent all round results with unscreened coke breeze :—

TABLE No. 26

Evaporative Test of Babcock & Wilcox Boiler and Chain Grate Mechanical Stokers with Balanced Draught, at Glasgow Corporation Gas Department, Temple Gas Works

Total heating surface	2531 sq. ft.
Stoker grate area	70 ,,
Ratio of heating surface to grate area	36·2 to 1
Duration of Test	24 hours
Fuel	Unscreened coke breeze
Size—Over $\frac{1}{2}$ in. to $\frac{7}{8}$ in.	15·4 per cent.
,, $\frac{1}{4}$ in. to $\frac{1}{2}$ in.	42·3 ,,
,, $\frac{1}{8}$ in. to $\frac{1}{4}$ in.	23·1 ,,
Under $\frac{1}{8}$ in.	19·2 ,,
Total quantity fired	40,320 lbs.
Consumed per hour (wet)	1,680 ,,
Consumed per sq. ft. of grate per hour (wet)	24·0 ,,
Consumed per hour (dry)	1,328 ,,
Consumed per sq. ft. of grate per hour (dry)	18·97 ,,
Combustible consumed per hour	1,010 ,,
Combustible consumed per sq. ft. of grate per hour	14·4 ,,
Riddlings	3 per cent.
Thickness of fire	9 ins.
Average steam pressure	110 lbs. per sq. in.
Temperature of water (well)	45° F.
Total water evaporated	196,400 lbs.
Average evaporation per hour actual	8,183 ,,
Equivalent evaporation per hour, from and at 212° F.	9,942 ,,
Evaporation per lb. of fuel, actual	4·87 ,,
Evaporation per lb. of fuel from and at 212° F.	5·92 ,,
Factor of evaporation	1·215 ,,
Draught	Forced
In blast flue	0·5 [1]
In ashpit	0·3 [1]
At rear fire door	Balanced
Thermal efficiency	67·4 per cent.

The machine firing of coke breeze *alone* in internally fired boilers, unless with a stationary grate, and the removal of clinker by hand, is not a satisfactory system of firing, owing to the low volatile content of the fuel.

[1] "The Manufacture of Water Gas," by Mr James Hall. Paper read before the Scottish Junior Gas Association, Western District, January 1923.

With water tube boilers two types of mechanical stokers have been successfully used, *i.e.* the travelling grate stoker and the chain grate stoker, both of which are described and illustrated in a subsequent chapter entitled " Furnaces and Firing."

The outstanding advantage of mechanical stokers of these types is in the slow and easily adjustable travel of the grate and fuel bed, and its uniform thickness. Further, while with hand fired furnaces the length of grate for efficient operation is limited to from 5 ft. to 6 ft., with these mechanical stokers grates from 14 ft. to 16 ft. long may be used, thus very considerably increasing the grate area and avoiding the necessity for rates of combustion in excess of the most efficient rate.

Another point of importance is that the fire is automatically cleaned, and manual labour in the handling of ash is entirely eliminated.

The length of travel of the fuel at a slow rate and at a uniform thickness, ensures very complete combustion and the residual clinker contains but the minimum of carbon.

The use of a very small and graded coke breeze containing a considerable proportion of dust does not present the same difficulty as is experienced in the hand firing of this small and light fuel, while the gain in efficiency as the result of working with closed doors continually is a factor of some importance.

The following comparative fuel costs of boilers fired with coal, coke, and coke breeze, tabulated by Mr E. W. L. Nicol, Engineer and Fuel Expert to the London Coke Committee, serve to show not only the economy derived by the use of breeze, but also the high thermal efficiency due to machine firing :—

TABLE No. 27

Comparative Fuel Costs of Boilers fired with Coal, Coke, and Coke Breeze

	Coal.	Coke.		Coke Breze.	
System of draught	Natural	Forced (London Coke Committee)		Impelled	
System of stoking	Mechanical	Hand		Mechanical	
Type of boiler	Water tube	Lancashire	Cornish	Babcock & Wilcox	
Grate surface, square feet	87·88	36·0	29·0	81·0	50·0
Fuel burned per square foot of grate per hour	26·9	15·0	16·1	25·2	28·28
CO_2 percentage	8·0	14·0	16·0	14·5	11·7
Excess air, percentage	130·0	48·0	28·0	43·0	75·0
Fuel loss, percentage	23·0	13·0	11·0	12·5	16·5
Calorific power as fired B.T.U.	12,000	12,000	12,000	10,083	9,018
Evaporation from and at 212° F. per lb. of fuel as fired	7·5 lbs.	9·8 lbs.	9·8 lbs.	7·84 lbs.	6·59 lbs.
Thermal efficiency	60·3 %	78·8 %	78·8 %	75·1 % [1]	71·01 % [1]
Current rates quoted f.a.s. London per ton	45/–	45/–	45/–	22/6	22/6
Fuel cost per 1000 gallons, evaporated	26/9	20/6	20/6	12/10	15/3
Financial saving effected	..	23 %	23 %	52 %	42 %

[1] Boiler only, no economiser or superheater.

It must be admitted that very slow progress is being made in the adoption of water tube boilers and machine firing in the larger gas works, but it is certain that with a wider appreciation of the outstanding advantages of thus utilising coke breeze for steam generation, the internally hand fired boiler will to a large extent be displaced by the machine fired water tube boiler—this change is inevitable.

For the utilisation of coke breeze with bituminous slack for steam generation in water tube boilers the Sandwich system of fuel blending, patented and introduced by Mr E. W. L. Nicol, Engineer and Fuel Expert to the London Coke Committee, marks a distinct advance in mixed firing.

This simple system, which is illustrated in Figs. 132 and 133, Chapter XII., has for its object the separate and distinct delivery from a double or divided hopper of fuels in superimposed layers. From the inner compartment of the hopper low grade slack coal is fed by gravity on top of a layer of coke breeze or coke, first fed from the outer compartment of the hopper.

Having determined by experiment the most suitable and efficient proportions of each fuel, the height of the delivery areas is fixed accordingly, and it is then only necessary to keep the compartments of the hopper supplied with the respective fuels.

It has been conclusively shown that this system of firing coke or coke breeze with bituminous slack possesses undoubted advantages over indiscriminate admixture, or even the most careful admixture of given proportions of two fuels.

The following comparative test figures (1) with slack and unscreened broken coke, and (2) with coal only, under precisely similar conditions with a Babcock & Wilcox boiler and economiser having a normal evaporative capacity of 6000 lbs. of water per hour, operating under natural draught, clearly demonstrates the efficiency and possibilities of this system of fuel blending :—

TABLE No. 28

	Test No. 1. Unscreened broken Coke and Slack.	Test No. 2. Coal only.
Calorific value as fired	11,138 B.T.U.	12,150 B.T.U.
Fuel consumed per sq. ft. of grate per hour	30·66 lbs.	31·66 lbs.
Ash and clinker, actual	16·22 per cent.	12·7 per cent.
Average steam pressure	178 lbs.	179 lbs.
Temperature of superheated steam	486° F.	490° F.
Water evaporated per hour	10,505 lbs.	8,747 lbs.
Water evaporated per sq. ft. of heating surface	5·22 lbs.	4·35 lbs.
Water evaporated per lb. of fuel as fired from feed temperature	7·18 lbs.	5·76 lbs.
Water evaporated per lb. of fuel from and at 212° F.	9·22 lbs.	7·44 lbs.
Efficiency, boiler and superheater,	69·9 per cent.	53·12 per cent.
Efficiency, boiler with economiser	79·96 ,,	60·98 ,,
Draught over fire	0·25 in.	0·25 in.

While coke breeze can no longer be regarded as a waste fuel although varying considerably in calorific value, and ash, and moisture content, it may in comparison with a large number of solid fuels available be frequently regarded as a low grade fuel.

What has been accomplished with coke breeze may also be accomplished with a variety of small and low grade fuels, which, at the present time, are not extensively used, and which from the point of view of calorific value, ash, and moisture content present no great difficulty in burning than breeze.

CHAPTER VI

TOWNS' REFUSE: ITS FUEL VALUE

THAT miscellaneous assortment of waste material generally known as towns' refuse, and which is periodically collected by the local sanitary authority, frequently at a heavy cost, usually comprises much material which might be and should be utilised by the householder to his own advantage, and to the benefit of the community.

The methods of disposal adopted by local authorities may be briefly stated as (1) tipping or dumping on so-called waste land, (2) disposal by fire in refuse destructors, and (3) recovery of the saleable material by mechanical sorting, in connection with what are known as refuse, salvage, or utilisation plants.

It is true that, in the case of a few towns on the seaboard, refuse has been disposed of by barging out to sea and dumping into deep water, but this method of disposal has never been regarded as satisfactory. Pulverisation of refuse and its conversion into a fertiliser, has been advocated, and this method of treatment has been adopted by a few local authorities. Tried on a large scale on the Continent it has not been found to be a satisfactory method of disposal, mainly because of the uncertain demand for the product.

The system which is still employed to a large extent in Great Britain, is the tipping or dumping of refuse on land. It is, however, not proposed to discuss this method of disposal which involves questions of sanitation and hygiene, which do not come within the scope or purview of this work. Disregarding the sanitary aspect of refuse disposal, the refuse tip or dump will be considered from the point of view of its value as a low grade fuel, which has been extensively used to displace coal, and which might and should be used to a far greater extent for this purpose.

It has been estimated that local authorities in Great Britain collect every year with house refuse from $2\frac{1}{2}$ to 3 million tons of cinder and recoverable coal, a large proportion of which is dumped to waste. This may be said to be equivalent in calorific value to from 500,000 to 600,000 tons of good house coal per annum. In other words, if this fuel were used by those who throw it away, the net result would be an annual saving of from 500,000 to 600,000 tons of household coal.

It cannot be too strongly emphasised that the value of a refuse destructor from the point of view of steam generation is to a large extent determined by the proportion or percentage of wasted household fuel contained in the refuse. Similarly the revenue derived from the mechanical sorting of refuse is affected to no small extent by the weight of saleable fuel recovered therefrom and its condition. In this chapter it is proposed to discuss the refuse destructor more particularly from the

point of view of the utilisation of the waste heat for the generation of steam, while in a subsequent chapter the recovery of fuel from waste will be discussed.

Nearly half a century has passed since the late Mr Alfred Fryer introduced the refuse destructor as a means of final disposal of refuse. Actually the first destructor cells or furnaces were built and put into operation at the Water Street Depot of Manchester Corporation in 1876, and it is believed that these were in use up to 1912, or even later.

As the earlier destructor furnaces have been exhaustively discussed in various text books, a brief description will now suffice. The cells or furnaces were arranged either in a single row comprising two or more furnaces, or back to back, the gases passing direct from the furnaces into a main flue leading to the chimney.

In the case of the smaller installations the main flue was arranged at the rear and beneath the furnace. With plants of larger capacity, where the furnaces were arranged back to back, the main flue was set at right angle to the grates, between and underneath the furnaces.

Each cell was completely isolated from the adjoining cell, discharging its gases into a common main flue.

The furnaces being operated under chimney or natural draught conditions, and the refuse being charged in at the top in considerable quantities at a time, the furnace temperature, as also the main flue temperature, was too low to ensure satisfactory combustion, with the result that complaints of objeetionable discharge from chimneys were frequent.

With a view to eliminating or minimising the offensive discharge from destruetor chimneys a device was introduced which was known as the "Fume Cremator." This comprised a small coke fired furnace, which was built in the main flue, at a convenient point between the destructor furnaces and the chimney, the gases passing from the furnaces over and through the "Fume Cremator" before reaching the chimney.

The function of the "Fume Cremator" was to render the low temperature and offensive gases innocuous. A number of these secondary or cremator furnaces were erected, but apart from the cost of firing the same with coke, the grate area usually provided, as also the cubic capacity of the furnaee, would appear to have been insufficient, having in mind the large volume of heavy gases passing from the destructor furnaces.

While the introduction of the fume cremator may be regarded as a serious attempt to enable the destructor to be operated without discharging offensive gases from the chimney, for reasons already referred to it cannot be said to have been altogether satisfactory.

The first real advance in the design of refuse destructors was in the provision of a forced draught air supply, which had the effect of eonsiderably increasing the furnace temperature, and accordingly improving the combustion eonditions, with the result that the gases discharged from the ehimney were usually no longer objectionable.

For some few years after the introduetion of forced draught the design of destructor cells or furnaces remained unchanged, these being arranged as distinet

and isolated units, from which the gases passed into a common main flue to the chimney.

Some twenty-five years since a drastic departure in the design of destructor furnaces was introduced, embodying (1) the provision of a continuous furnace chamber and grate, with divided or separate ashpits ; (2) a combustion and dust interception chamber, which was usually arranged at right angles to the grate ; (3) the setting of a steam boiler beyond the combustion chamber ; and (4) the provision of a regenerator or continuous air heater between the boiler and the chimney. The high temperature waste gases were used in connection with the boiler for steam generation, and upon leaving the boiler were further utilised for heating the whole of the air supply for combustion.

There can be no doubt that these improvements in furnace design, and in the provision of a heated air supply for combustion, constitutes the greatest advance made in destructor design, and while within recent years many valuable improvements have been introduced in the form of mechanical charging and clinkering, as also in less important details, which will be hereafter referred to, the continuous grate, combustion chamber, and the use of hot air for combustion are embodied in almost every modern installation, and are now regarded as essential.

Writing in 1912 [1] upon the question of comparative design the author put the position thus :—

" As one who has devoted much time and attention to the development of the continuous grate system for many years past, the author may perhaps be forgiven for an unusual enthusiasm. This type has in practice been proved to show a working efficiency far in advance of that previously obtained, both with the best, and also the most inferior refuse.

In destroying refuse of very low calorific value, or with a high percentage of moisture, the continuous grate possesses manifest advantages over the isolated cell system. Refuse can be efficiently burned with the former, which it is very difficult, if not impossible, to burn with the latter type.

In the maintenance of a high working temperature in the furnace and combustion chamber, in the avoidance of nuisance, in power production, and in maintenance cost, it has been amply demonstrated that the continuous grate marks a great advance upon previous practice.

" It is only since the introduction of this type that the power production aspect of refuse disposal has become a prominent feature. The easy maintenance of a reasonably constant steam pressure, which is governed entirely by a well-maintained furnace temperature, has done much to convince those who wish to use the steam that the supply is a satisfactory one.

" During the past ten years comparatively few cellular destructors have been erected. For every destructor of this type which has been built during this period, at least five destructors of the continuous grate type have been erected.

" There could be no more conclusive proof of the all-round superiority of the continuous grate type than the fact that this type is now offered by every destructor

[1] See "Modern Destructor Practice," 1912, by the author.

maker in England, with but a single exception. In America it is the standard British type, and in continental and tropical countries it is generally recognised as of vital importance."

For some years following the introduction of the continuous grate design, destructors were made in three distinct types, in so far as charging is concerned (*a*) front fed, (*b*) back fed, and (*c*) top fed. With the former type the refuse was hand fired direct on to the grate, the clinker being also removed through the firing doors at the front. In the case of the back fed type of destructor a drying hearth was usually provided, the refuse being shovelled on to this hearth, and after drying, was spread over the grate—the clinker being removed at the front of the furnace from points directly opposite to the charging doors.

The top fed destructor, in common with the back fed type, was provided with a drying hearth, this being arranged at the upper part of the grate and directly beneath the charging opening. From the drying hearth the refuse was levelled and spread over the grate as required, this work being done from the front of the furnace through the openings, which were also used for the removal of clinker.

Subsequent improvements which were introduced, and which will be discussed, had for their object the mechanical charging of top fed destructors (1) with a view to eliminating manual labour in charging, and (2) to provide for the direct charging from mechanically operated receptacles of definite and known quantities at regular intervals.

While these improvements were satisfactory in the reduction of manual labour on top of the furnace, the dumping of a heavy charge of refuse on to a limited grate area presented extremely unsatisfactory conditions for combustion, in addition to which too much labour was necessitated at the front of the furnaces in spreading and levelling the charge over the grate.

The Charging of Destructor Furnaces.—The methods of charging or feeding refuse into destructor furnaces has for many years been the subject of recurring and even acute controversy.

The great bulk of destructor installations in Great Britain and in other countries may be said to comprise hand charging, either at the top, back, or front of the furnace.

Top Feeding.—Top feeding was thus tersely defined by Mr George Watson[1] twenty-five years since: "With top feeding the refuse is merely pushed blindly in."

This may be said to accurately describe the operation, not only in connection with the top-fed furnace as designed nearly fifty years since, but the plain top-fed destructor of to-day.

With all destructor furnaces of this type, almost invariably the capacity of the charge introduced is determined by the man or men on top of the furnace. No regard is paid to weight or cubic capacity, the only limiting factor is the cubic capacity of the furnace. The charge may be half a ton or it may be three times

[1] Watson on "Refuse Furnaces." *Proceedings of the Institution of Civil Engineers*, vol. cxxxv., Session 1898-99, Part 1.

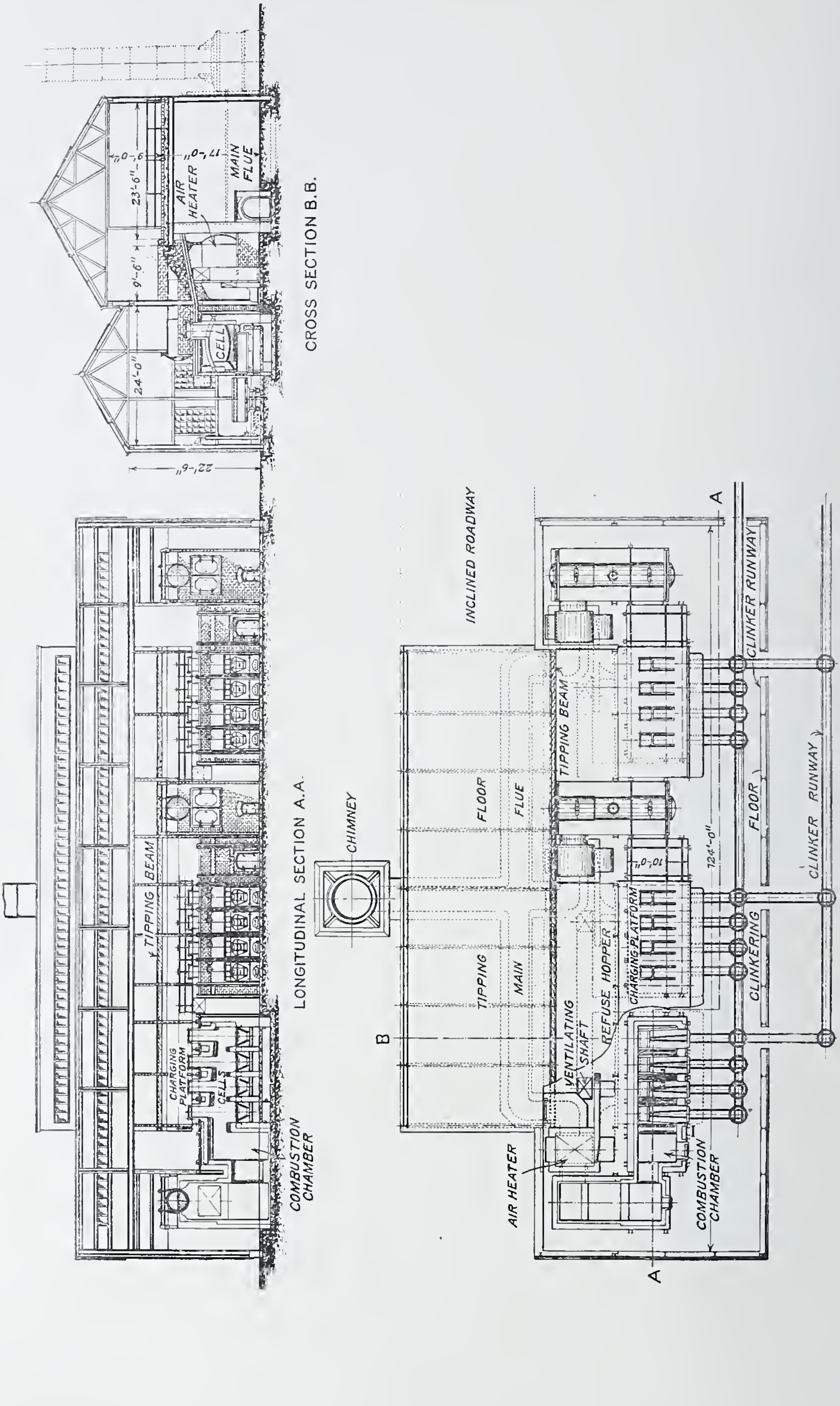


Fig. 33.—Twelve Direct Top Hand-fed Trough Grates, with Boilers, Air Heaters, Fans, and Chimney.

this quantity. As a general rule the charges introduced are far too heavy: a heavy charge is favoured, because it means a periodical idle spell.

This method of charging, it need scarcely be observed, is opposed to the most elementary principles of combustion. From the point of view of steam generation it is most unsatisfactory and inefficient, it usually involves filthy conditions within the destructor house and serious risk of nuisance outside, it necessitates the use of excessive air pressure in the ashpits and conduces to the emission of dust and unconsumed light material from the chimney, and the production of unsatisfactory clinker.

Back Feeding.—A considerable number of back shovel-fed destructors are in use of several makes, both in Great Britain and elsewhere. The outstanding advantage of this type is that a drying hearth is used, and the clinker is withdrawn at the opposite side of the furnace, *i.e.* the furnace is charged at the back, and clinkered at the front. The principal disadvantage is that the labour is required at two points and cannot be concentrated.

Front Feeding.—Many front shovel-fed destructors of various makes have been adopted, mainly in Great Britain, having a maximum capacity of 120 tons daily, to a minimum capacity of about 5 tons daily or even less.

Furnaces of this type represent the utmost simplicity in design; as a general rule no drying hearth is used, the whole of the refuse being shovelled on to the grate direct; all labour is concentrated at the front of the furnace, the clinker being removed at this point through the firing doors.

Considered from the standpoint of efficiency in steam generation, shovel-fed destructors, both of back and front-fed types, have invariably given results considerably in advance of those obtained with top-fed furnaces, as also a much more vitreous clinker. Further, it may be observed that the actual labour cost per ton of refuse destroyed is usually less with a shovel-fed furnace than with a top-fed furnace.

While shovel feeding has been much favoured in Great Britain, mainly because of its simplicity and the uniformly good results obtained, in continental countries this system of charging has been strongly opposed on hygienic grounds, and has accordingly made but little progress. Modern examples of top-fed, back-fed, and front-fed Heenan destructors are shown in the following illustrations.

Fig. No. 33 shows twelve top direct hand-fed trough grates, arranged in three units of four cells each, with three Babcock & Wilcox water tube boilers, air heaters, fans and chimney.

In Fig. No. 34 is shown six back-fed trough grates, arranged in two units, with two Babock & Wilcox boilers, air heaters and chimney.

A large plant of the front-fed flat grate type is illustrated in Fig. 35, this plant comprising twelve grates, arranged in two units of six grates each, with two Babcock and Wilcox water tube boilers, air heaters, fans and chimneys.

In Figs. 36 and 37 are shown views of the feeding and clinkering floors respectively of a three-grate back-fed destructor erected for the Redditch Urban District Council.

Mechanical Charging.—During the past twelve years there has been an insistent

demand for the mechanical charging of refuse, mainly with a view to improving the conditions in the destructor house, and also to reduce the labour cost.

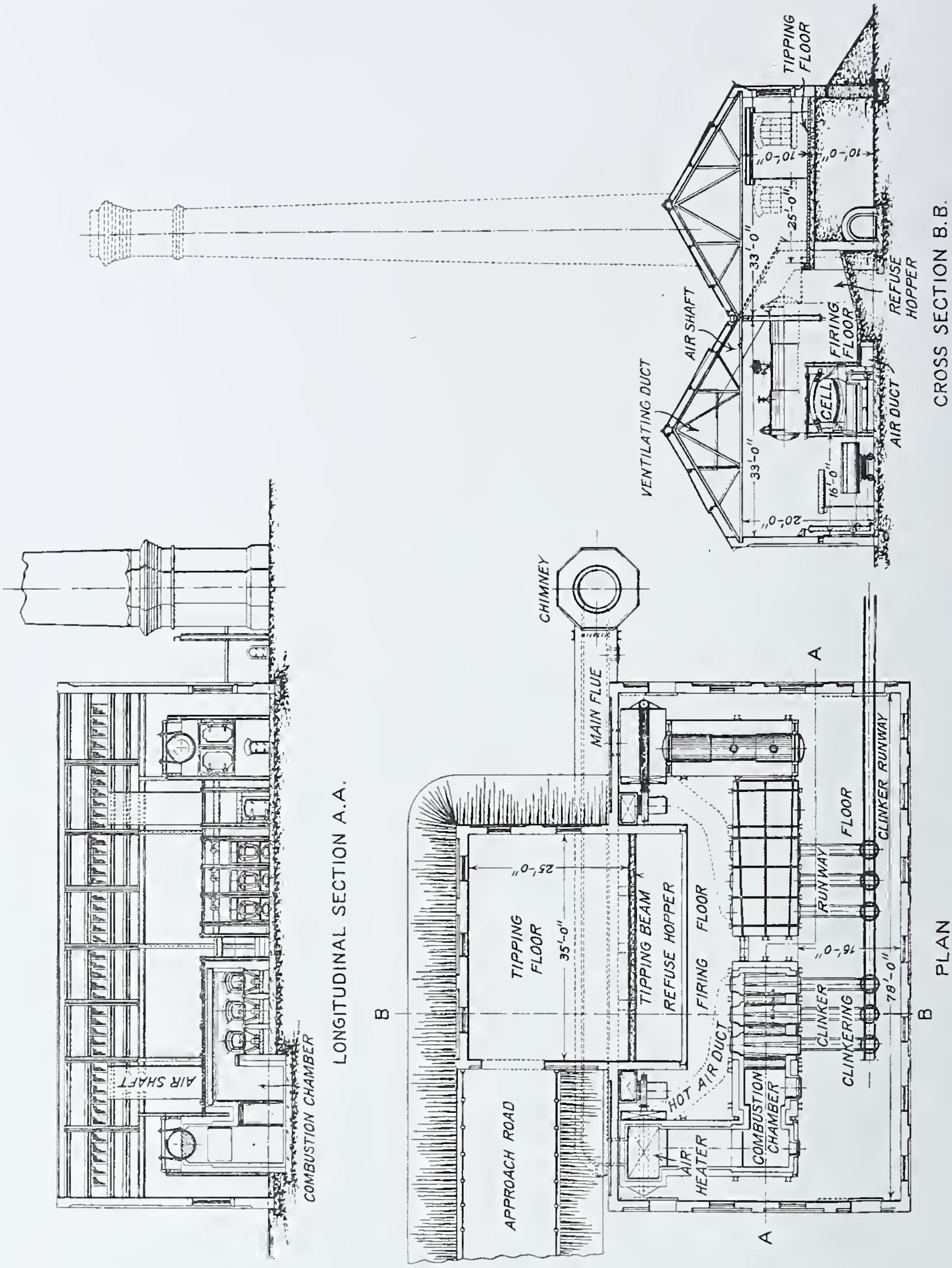


FIG. 34.—SIX BACK-FED TROUGH GRATES, WITH BOILERS, AIR HEATERS, FANS, AND CHIMNEY.

Since the first system of mechanical charging was introduced some twenty-five years since, various patents have been granted for devices having for their object the charging of destructor furnaces with the minimum of manual labour.

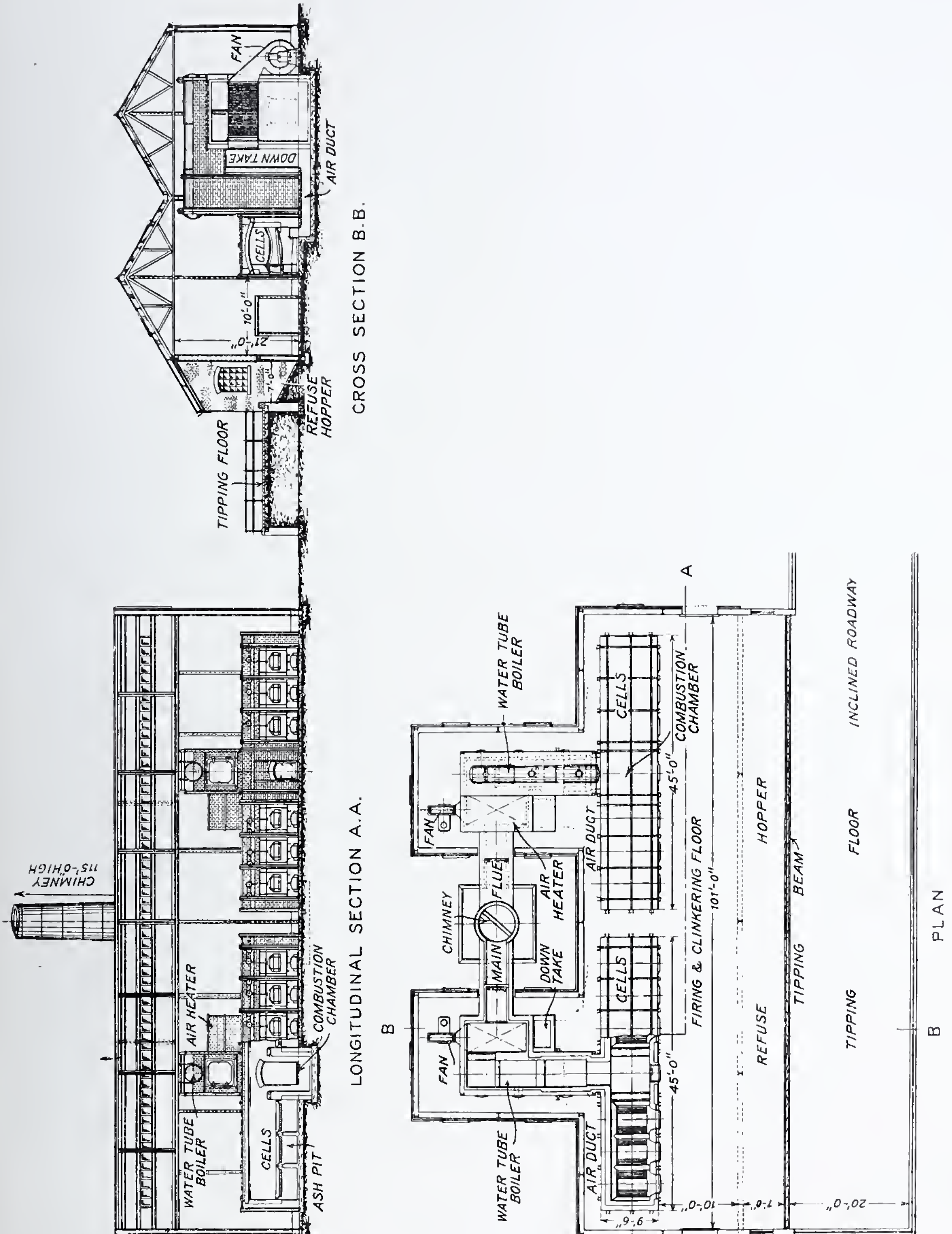


Fig. 35.—Twelve Front-fed Flat Grates, with Boilers, Air Heaters, Fans, and Chimney.

Some have been too complicated and not sufficiently flexible for the conditions demanded in the destructor house. Nearly every mechanical charging device introduced until within the past decade has possessed the fatal defect of having been designed to handle far too heavy a charge of refuse, and providing little or no flexibility either in regard to weight or cubic capacity.

Apparatus has been used for the instantaneous dumping into a furnace of two tons of refuse or even more, the compact mass on the grate being from 5 ft. to 6 ft. thick, and presenting impossible conditions from the point of view of efficient combustion.

In 1912, when writing on systems of charging destructors, the author expressed the following opinion [1]: " There are already distinct signs that the top-fed destructor of the future will embody apparatus by which each charge will be definitely measured, while the charges will be comparatively small—about one cubic yard—and the operation of charging will be controlled by the man in charge of the destructor at the clinkering floor level."

While it is usually unwise to prophesy, actually the developments in mechanical charging have very closely followed on the lines of this forecast.

Mechanical charging may now be said to be satisfactory, because the principles governing combustion have been studied and observed. Instead of introducing refuse—as a low grade fuel—by the cartload or wagon load, it is now directly and instantaneously charged in very moderate and comparatively small quantities, which may be varied, the capacity of the delivery receptacle being decided upon after a careful examination of the refuse.

Messrs Heenan & Froude, Ltd., the well-known destructor makers who have devoted such close attention to the saving of labour and the improvement of the operating conditions in connection with refuse destructors, have introduced and put into use two distinct systems of mechanical charging which will be briefly described :—

Container Feed.—With this system the refuse container may be either rectangular, vertical, or inclined, or a cylindrical, vertical or inclined receptacle containing the charge, which, as already observed, should be a moderately small quantity.

The containers may be filled by hand, the refuse being shovelled, pushed, or raked in, or they can be filled by a grab attached to a transporter or crane, or by means of special skips with doors permitting of the automatic discharge of the refuse during the lowering operation.

When the containers are charged from a grab or skip they are usually of special breech-shaped design, with divergent legs, each leg containing a charge.

Mono-rail grab transporters electrically operated are frequently used for picking up the refuse, which is stored in hoppers at ground level, raising, transporting, and discharging the same into containers. The grab used is of special design, with suitable tines adapted for picking up material so variable in composition as towns' refuse.

In practice it is found that the grab picks up from two-thirds to three-fourths of its actual total capacity.

[1] " Modern Destructor Practice," by the author, 1912, page 38.

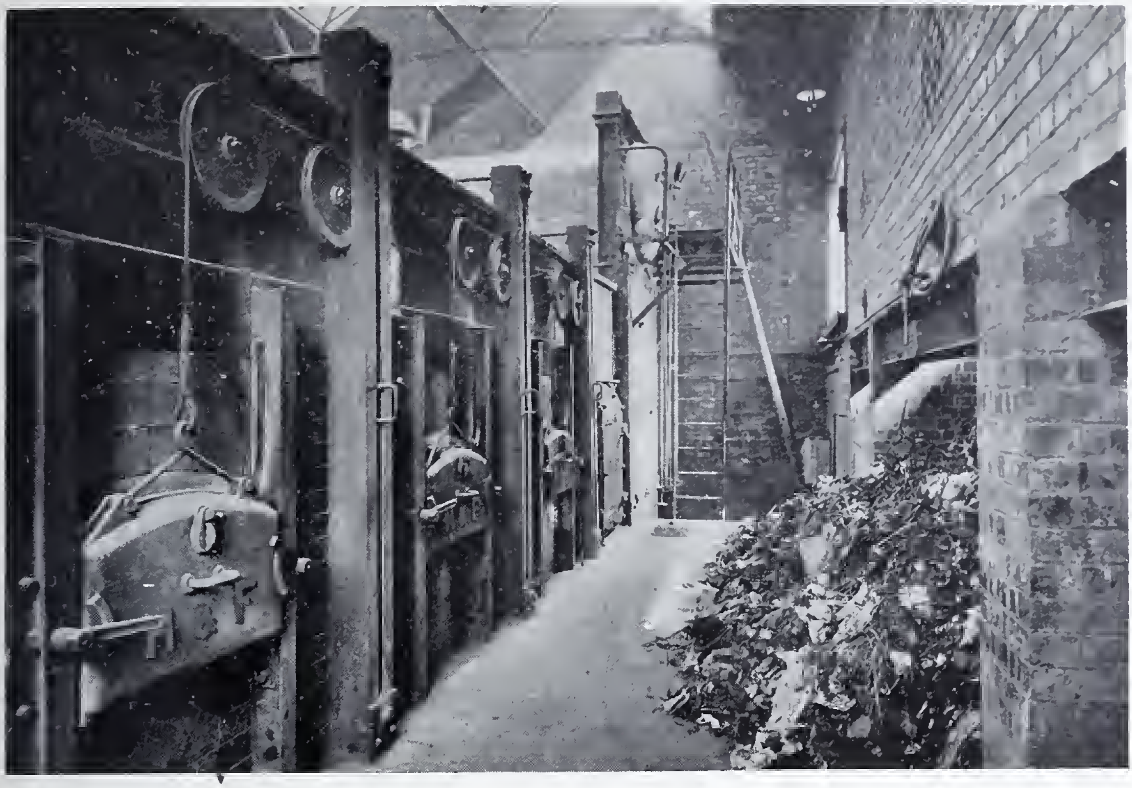


Fig. 36.—Feeding Floor, Heenan Back-fed Destructor, Redditch.

Fig. 37.—Clinkering Floor, Heenan Back-fed Destructor, Redditch.

With a grab system it is essential that suitable provision be made to prevent the dissipation of dust throughout the atmosphere in the destructor building. In picking up the refuse and discharging it from the grab into the refuse container, a special type of dust bell is provided. This dust bell totally encloses the grab and prevents any dust or other matter from falling into the building when the transporter is in motion.

Skip Feed.—With the skip feed system the skips, which may be used for collecting and storing the refuse, or for both purposes, take the place of containers. Special doors are provided both at the top and bottom of the skip, which is lowered by means of a crane on to a specially designed framework or seating, supported about the furnace charging door ; and so constructed that the weight of the staging, the skip and its contents are independent of the furnace structure. Mono-rail transporters or electric travelling cranes convey the skips from the skip pit or the skip storage platform to the charging stage.

The provision for spreading the refuse over the grate as necessary is by means of a small auxiliary door fitted on to the clinkering door ; by means of this arrangement the inflow of cold air during charging and spreading is reduced to the minimum.

The mechanical charging of destructor furnaces essentially differs from the mechanical charging of coal. For instance, in the mechanical charging of a horizontal gas retort, the charging machine, with its charging platform having been put into position in front of the retort, with the platform level with the bottom of the retort, the complete charge is pushed bodily into the retort.

On the contrary, the mechanical charging of refuse involves only *mechanical control of the doors*, which permit the fall *by gravity* of the refuse from the container or skip into the furnace chamber.

The three systems of mechanical control introduced by Messrs Heenan & Froude, Ltd., may be described as follows :—

(1) Hand operation from the clinkering floor.
(2) Hydraulic operation with ram cylinders on platforms at the level of the top charging doors.
(3) The use of electric motors for the opening and closing of the doors, this operation also being controlled from the clinkering floor.

Hand operation from the clinkering floor takes slightly longer than the power-operated systems, but all three methods ensure practically instantaneous charging.

In each case the doors are sealed to prevent the escape of fumes into the building ; the seal used is a special asbestos preparation in preference to a water or sand seal, the former being a source of constant trouble, while the latter is ineffective.

Fig. 38 illustrates six top container fed trough grate cells arranged in two units, with two Babcock & Wilcox water tube boilers, air heaters, fans and chimney, while in Fig. 39 is shown eight top container and grab fed trough grate cells arranged in a single unit with one Babcock & Wilcox water tube boiler, air heater, fan and chimney.

Clinkering.—The removal of clinker from destructor furnaces by hand is extremely heavy and objectionable work, owing to the frequency of the operation, the proportion or weight of material to be removed, and the exposure to radiation, dust and fumes.

With an ordinary grate of, say, 25 to 30 sq. ft. area, given a rate of combustion

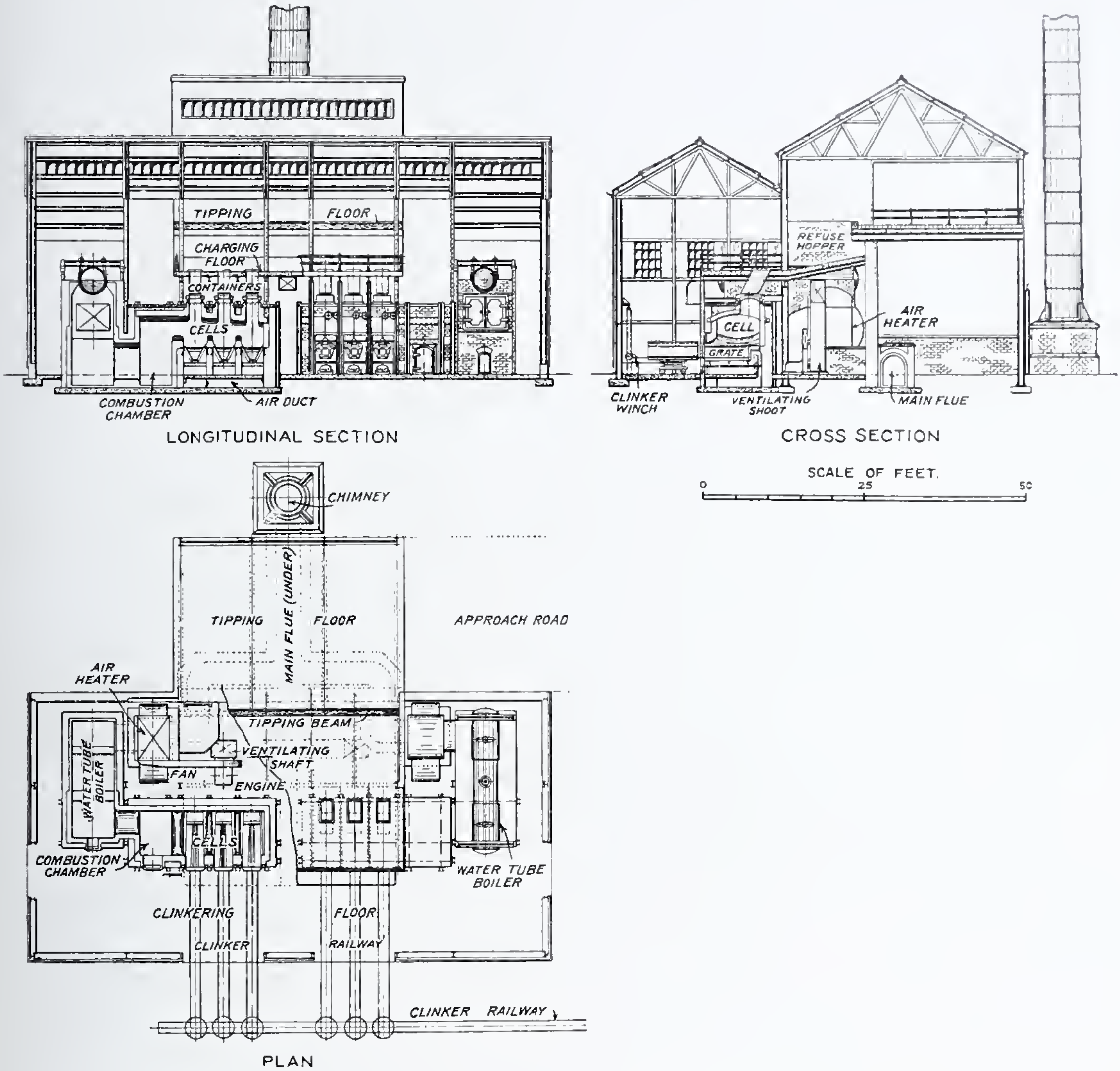


Fig. 38.—Six Top Container Fed Trough Grates, with Boilers, Air Heaters, Fans, and Chimney.

of 50 lbs. per sq. ft. of grate per hour, it is usually necessary to thoroughly clean the fire, *i.e.* to remove all clinker at intervals of about $1\frac{1}{2}$ hours.

The weight of clinker to be removed—depending upon the character of the refuse—will probably be not less than from 5 to 6 cwts., and possibly more. As a general rule this involves keeping the door open for from ten to twenty minutes, during which time there is a constant flow or inrush of cold air into the furnace chamber, detrimentally affecting the maintenance of a uniform temperature in the

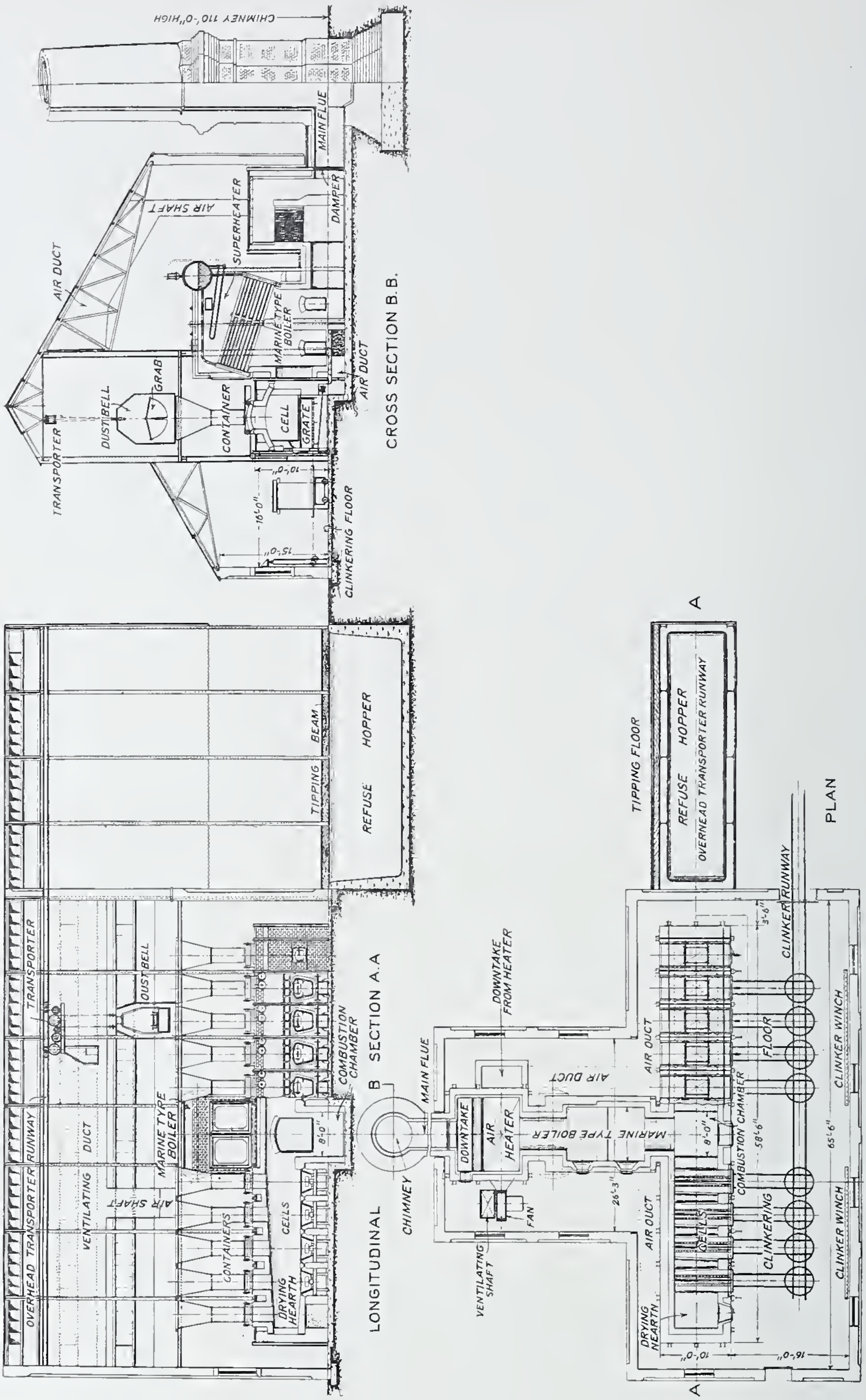


FIG. 39.—EIGHT TOP CONTAINER AND GRAB FED TROUGH GRATES, WITH BOILER, AIR HEATER, AND CHIMNEY.

furnace and combustion chamber, reducing by dilution the temperature of the gases to the boiler, involving a drop in steam pressure in the boiler, and, in turn, a reduction in the temperature of the hot air supply to the furnaces, at the very time when it would be most advantageous to have an increased air temperature.

Further, these variations in the furnace temperature due to the extent and number of inactive periods, and the inrush of cold air, lead to deterioration of the furnace fittings and the firebrick linings.

It will therefore be evident that it is desirable to carefully consider the advantages of mechanical clinkering, not alone from the point of view of saving labour, but to ensure more uniform temperature conditions in the furnace and combustion chamber, and consequently increased efficiency in operation; to ensure the fluctuation in steam pressure being kept within the closest possible limits, and to reduce the cost of maintenance.

The simplest and most efficient system of mechanical clinkering yet evolved is known as the Trough Grate, which was introduced by Messrs Heenan & Froude, Ltd., some ten years since, and which has been extensively adopted.

The trough grate, as will be suggested by its name, is "V"-shaped, and apart from the facility with which clinker is removed by reason of the form of the grate, provides for much easier charging than the usual type of flat, horizontal, or slightly inclined grate, while also demanding less skill.

The trough grate may be readily filled from the front, back, or top, either by hand or by mechanical means, and owing to the formation of the grate, to a large extent spreading, levelling, or trimming is eliminated.

The makers claim that owing to the form of the grate and the disposition of the air spacing or orifices, the forced draught air supply is concentrated upon the body of fuel lying in the trough. It is further claimed that blow holes, which to a large extent are inevitable with the ordinary type of flat grate, are impossible with the angle of air delivery. This would appear to be a perfectly sound claim, with which the author is in complete agreement, when the air is delivered into the mass of fuel *transversely* instead of vertically the trouble due to blow holes and consequent excess of air is no longer possible.

This trouble with ordinary or flat grates is constant, and the remedy is as bad as the trouble, inasmuch as the surface of the fire must be constantly watched, and when a blow hole develops the opening must be filled with refuse, either by spreading or shovelling. In practice it is invariably found that firemen will not do this, and it is no uncommon experience to be able to simultaneously observe a dozen blow holes in a fire.

It is further claimed by the makers that the clinker produced is harder; the author would prefer to put it that the clinker *may* and *should* be harder than ordinary destructor clinker. Whether it actually is or not will depend upon care in operation and the thorough burning through of a charge. Without proper care there is a risk of withdrawal while leaving a soft and unburned core in the centre of the mass. This criticism is not directed at the trough grate, on the contrary

unsatisfactory clinker will be due to lack of works organisation or management, with no proper cycle of operation.

The most important advantage derivable from the trough grate is in the facility with which the mass of clinker may be removed, involving but a relatively small effort upon the part of the fireman.

During the combustion process, as the clinker solidifies, and without adhering to the sides or ends of the trough grate, it settles upon the removable base of the trough, which is arranged in the form of a draw bar set in a channel or groove.

This draw bar is withdrawn by means of a hand or power winch, and with it is removed the whole body of clinker in a single operation, and in a fraction of the time involved in clinkering by hand.

The effect is to very greatly reduce the inactive periods, and accordingly increase the burning capacity of the furnace, probably to the extent of at least 25 per cent., while reducing to the minimum the loss and inefficiency due to the inrush of cold air. As the solid mass of clinker is withdrawn from the furnace it is placed upon a specially designed truck, the body of which may be of either the open or enclosed type as preferred. The saving in time and labour will be obvious, in addition to which the inconvenience and nuisance due to the dissemination of dust—which is inevitable with hand clinkering,—is to a very large extent avoided.

Those who have had any considerable experience in the operation of refuse destructors will doubtless agree with the author that mechanical clinkering should supersede hand clinkering in all destructor works irrespective of size, as apart from the saving in labour the advantages in improved operating efficiency are beyond question.

The Heenan patent trough grate is illustrated in Figs. 40 and 41, the former showing the withdrawal of clinker in connection with the two-grate plant at Hertford, while the latter is an internal view of a trough grate.

The Air Supply for Combustion.—Prominent among the improvements introduced in connection with destructor furnaces is the use of hot air for combustion, to which reference has already been made.

For the heating of the air supply, the waste gases are utilised after leaving the steam boiler. The apparatus used, which has been termed a regenerator or recuperator, may be described as a nest of cast-iron tubes attached at the top and bottom to tube plates, the whole being fixed in a firebrick lined chamber.

The waste gases leaving the boiler pass through the cast-iron tubes, while the air is either induced or forced to flow over the external and heated surfaces of the tubes, and from the air heater chamber is delivered through ducts or conduits to the ashpits of the furnaces, and forced through the fires.

The outstanding advantages of using heated air may be briefly stated thus :—

The ignition of freshly charged refuse is much accelerated owing to the rapid liberation of moisture. There is a substantial increase in the furnace and combustion chamber temperatures as the result of the added heat units and the reduction in the volume of excess air and reduced dilution of the gases, with a consequent improvement in the evaporative efficiency.

In destructor furnaces the question of rapid ignition is of paramount importance, particularly if the waste heat is utilised for steam generation; sluggish ignition adversely affects the furnace and combustion chamber temperatures, involving fluctuating steam pressure.

For the efficient burning of sub-tropical and tropical refuse, apart from any question of steam generation, it may be observed that the use of heated air is essential.

In connection with all well-designed modern destructor installations, adequate positive ventilation of the building is ensured by taking the air supply for com-

Fig. 40.—The Heenan Patent Trough Grate, showing Withdrawal of Clinker.

bustion from the building by means of suitably arranged air ducts to the air inlet of the regenerator.

In practice for many years past this has been found to be very effective, as the air supply within the building is thus changed several times every hour.

The most suitable Steam Generator.—In any consideration of towns' refuse as a low grade fuel the type of steam generator claims attention.

Hitherto steam boilers of the Lancashire, Cornish, and water tube types have been adopted, and a considerable number of each type are now in use in Great Britain, although in other countries water tube boilers are almost exclusively used.

While boilers of the Lancashire and Cornish types have given excellent results

in steam generation, there can be no doubt that the water tube boiler is the most suitable and efficient type for the utilisation of waste heat.

Regarded from the points of view of compact heating surface, facility in building in, saving in ground space, accessibility for cleaning, and for independently firing if desired; when the destructor is shut down, the water tube boiler offers advantages not obtainable with boilers of other types.

Although Lancashire and Cornish boilers have and are giving complete satis-

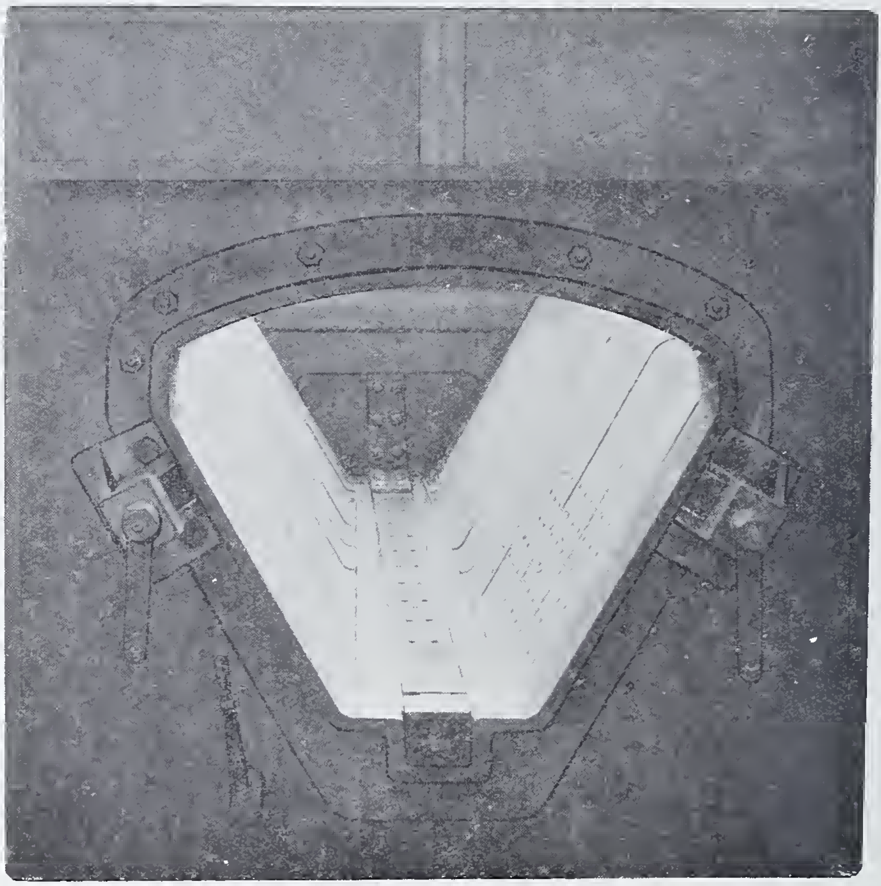


Fig. 41.—The Heenan Patent Trough Grate (Internal View).

faction in steam generation, they provide convenient facilities for the deposit of dust. The connecting tubes between the combustion chamber and the boiler, the furnace tubes, the side flues, and flame bed, all provide space for the deposit of dust, with the result that in a comparatively short period the effective heating surface is reduced and the efficiency is impaired, back draught is experienced, and the plant must be shut down for cleaning, which necessitates a preliminary three or four days for adequate cooling.

With the water tube boiler the facilities for dust removal are such as to enable longer continuous operation periods, and much more expeditious removal of dust.

Even if the dust is removed by a suction or pneumatic system, the water tube

boiler is much more convenient than the Lancashire or Cornish types, because of its greater accessibility for easy and rapid cleaning. The author is well aware that boilers of other types have been advocated, such as for instance the multitubular or fire tube boiler. Those who purpose utilising refuse as a fuel, however, would be well advised under no circumstances whatever to instal a boiler of this type, or indeed of any similar type. In the utilisation of dust-charged gases for steam generation, it has been shown, as might have been anticipated, that the fire tubes rapidly choke, involving back draught, increased maintenance cost, inefficiency, and very frequent stoppages for cleaning.

While from every point of view the water tube boiler may be regarded as the most efficient type of steam generator for combination with a refuse destructor, it does not possess the advantage of the Lancashire and Cornish types in providing large steam and water space, which in readily meeting steam requirements for certain loads is very beneficial.

To some extent this deficiency may be remedied by providing a main steam and water drum of larger diameter than is usual.

It is good practice under such conditions when installing a water tube boiler of a given heating surface, having normally a standard main drum of 3 ft. diameter, to provide instead a drum of 4 ft. diameter.

In connection with sewage pumping stations and air compressor stations, where as the result of sudden and heavy rainfall an unusual demand for steam has at times to be met quickly, the author, who has invariably used drums in excess of the standard diameter, has found the increased steam and water storage of undoubted advantage.

The Fuel Value of Towns' Refuse.—From the point of view of calorific value and composition generally, towns' refuse must be regarded as the lowest of all low grade fuels.

If it were not for the fact that it is desirable for sanitary reasons to dispose of the refuse of communities by the agency of fire, certain it is that as a potential fuel, that heterogeneous mixture known as towns' refuse would not receive any consideration.

Regarded strictly as a fuel it may be said that towns' refuse is certainly inferior to other low grade and waste fuels which are now being utilised for power production, in addition to which, unlike all other low grade fuels of more or less constant composition and calorific value, towns' refuse varies widely in its component parts, apart altogether from seasonal influences.

While the composition and calorific value of refuse in Great Britain often shows a considerable variation even under identical or analagous climatic conditions, refuse in other countries, temperate, sub-tropical, and tropical, varies to a large extent in its composition and fuel value.

In the accompanying Table No. 29 is shown the comparative composition of refuse, as determined by screening, in eight cities and towns in England and Scotland.

These analyses clearly reveal two important features in the composition of refuse: (1) the high proportion of fine dust, and (2) the very large percentage of cinders.

Comparing these figures with other records of various analyses made during

the past twenty-five years, it is shown that in the main the composition of towns' refuse has not changed appreciably, in so far as the percentage of cinders is concerned.

TABLE No. 29

Comparative Composition of Refuse as determined by Screening

	Lancashire.	Lancashire.	London.	Lincolnshire.	Lancashire.	Devonshire.	Yorkshire.	Scotland.	Average.
	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.	P. cent.
Fine dust	54·75	40·2	53·2	32·5	95·5	52·00	58·8	49·99	47·74
$\frac{1}{2}$ in., $\frac{3}{4}$ in. and large cinders	32·44	51·5	43·2	34·2		29·26	30·9	37·36	36·24
Bricks, pots, shale, etc. .	10·22	2·93	..	2·8	1·11	4·50	8·58	4·96	4·73
Tins	0·99	1·01	0·09	2·8	1·19	2·25	1·0	0·88	1·46
Rags	0·52	0·44	0·25	0·3	0·24	0·46	0·4	0·72	0·55
Glass	0·53	0·99	0·34	1·2	0·46	..	0·6	1·12	0·75
Bones	0·04	..	0·09	0·09	..	0·30	0·09	0·13	0·15
Vegetable refuse . .	0·22	1·0	0·37	16·2	..	7·30	1·3	1·88	3·25
Scrap iron	0·15	..	..	0·1	0·18	...	0·1	0·10	0·08
Paper	0·8	1·33	1·0	0·8	1·24	2·50	0·06	0·91	1·33
Fish, offal, greens, small paper, bags, carpet, oilcloth, boots, etc.	..	..	..	8·5	..	1·00	..	1·95	..

While, as a general rule, the results obtained in steam generation under test conditions are rightly regarded with some suspicion, the author has thought it desirable to set forth the figures as given in Table No. 30, with a view to showing the comparative results in steam generation obtained in some seven different countries and several English counties, covering practically every month in the year, and with test periods varying from 7 to 189 hours.

The author is well aware that evaporative tests are usually carried out with a trained staff and under specially favourable or prepared conditions, such as would not ordinarily obtain. Further, it may be stated that the real test is the performance under ordinary or normal conditions over an extended period.

Although attaching no undue importance to the test figures quoted, and estimating the same at their proper value, nevertheless these figures are well worth careful study, showing as they do that in such a hot month as January it was possible in Melbourne to obtain an average evaporation of $1\frac{1}{2}$ lbs. of water per lb. of refuse destroyed over a period of $13\frac{3}{4}$ hours.

The results obtained at Aberdare, Pontypridd, Rotherham, and Coventry, in the vicinity of coal-fields, clearly indicate a high proportion of carbon in the refuse, and an extraordinary waste upon the part of householders.

At Milwaukee the results obtained both under extreme winter and summer conditions show that the high proportion of garbage contained in Milwaukee refuse in the summer months does not reduce the evaporation to the extent which might be anticipated.

The evaporative results obtained at Penang and Singapore are such as might be anticipated, having in mind the climatic conditions and the composition of the refuse, with a very low percentage of material possessing any appreciable calorific value, and a large proportion of waste having a very high moisture content.

TABLE No. 30

Steam Generation from Refuse

Heenan Destructor at	Evaporation per lb. of refuse from and at 212° Fahr., (lbs.).	Month of Test.	Duration of Test in Hours.
Ilford, Essex	1·82	March	10·0
Richmond (Melbourne), Australia	1·50	January	13·75
Westmount (Montreal), Canada	2·11	March	9·5
Milwaukee,[1] Wis., U.S.A.	1·31	..	37·0
East Grinstead	1·88	June	7·5
Aberdare, South Wales	4·22	,,	8·85
Rotterdam, Holland	1·1053	February	..
Ipswich, Suffolk	1·57	April	7·0
Pontypridd, South Wales	3·47	February	8·0
Swinton and Pendlebury, Lancs.	1·635	September	11·0
Clydebank, Scotland	2·11	May	8·5
King's Norton	2·63	February	13·25
Bury St Edmunds, Suffolk	2·04	December	7·33
Cheltenham, Glos.	1·577	June	17·5
Redditch, Worcs.	1·9	November	7·5
St Albans, Herts	2·75	January	8·125
West Bromwich	1·76	..	8·5
Rotherham, Yorks.	2·075	January	18·0
Penang,[2] Straits Settlements	0·506	April	8
Singapore, ,, ,,	0·31	June	72
Coventry,[3] Warwick	2·298	February, April, July, September	189

In Table No. 30 the remarkable average results obtained at Coventry over a period of 189 hours are included. These results are so exceptional and conclusive that it has been thought desirable to include complete details.

The complete details of the tests are given in Table No. 31, while in Figs. 42, 43, and 44 are diagrams prepared by Mr J. Eric Swindlehurst, M.A., A.M.I.C.E., Deputy

[1] Extreme winter—extreme summer = ·96.
[2] By-pass damper full open throughout the test.
[3] Average of four tests aggregate 189 hours.

TABLE No. 31

Coventry Official Destructor Tests, 1910-1911

	No. 1.	No. 2.	No. 3.	No. 4.	Average guarantee.		Remarks.
Date of test	Sept. 27–30	Feb. 7–10	April 25–28	July 11–14			From separate test carried out per cent. of steam for forced draught purposes=4·4 per cent.
Total test hours (*i.e.* hours of normal burning) . . . hrs.	51·878	45·932	48·7	42·49	189·0		
Total weight of refuse burnt . . . lbs.	543,488	449,736	453,208	449,204	1,805,636	Totals	For boiler feed water pumps, 2 economisers, engines and pump lifting feed water from hot well to tank=2·39 per cent.
,, ,, ,, . . . tons	202·45	200·775	203,325	200,537	806·087		
Rate of burning per hour (for 2 units) . lbs.	8,774	9,772	9,334	10,572	9602·5		
,, ,, ,, ,, . tons	3·917	4·34	4·16	4·719	4·284	4·11 tons	
Rate of burning per sq. ft. of grate area per hour . . . lbs.	56·3	62·7	59·79	67·79	61·77	59·0 lbs.	Marshall engine driving clinker elevator, crusher, mixer and mortar mill =4·89.
Equivalent rate of burning per 24 hours . tons	94·0	104·09	99·96	113·22	102·82	98·6 tons	
Actual evaporation of water (metered) . lbs.	823,690	930,600	910·500	681,300	3,346,090	Total	
Evaporation per lb. of refuse burnt . . lbs.	1·815	2·069	2·007	1·517	1·858		
Average boiler pressure (gauge) . . lbs./sq. in.	197·9	192·8	184·95	192·4	192·0	185 lbs./sq. in.	Total=11·68 per cent. Guarantee=15·1 per cent.
Average temperature of feed water . . ° Fahr.	99	106·8	94·06	109·13	102·5		
,, ,, of steam superheated . ° Fahr.	538	504·4	487·9	525·11	513·8	See remark [2]	[2] Superheaters were originally designed to give 100° F. of superheat at the end of 300 ft. of steam pipe. Since installation the capacity has been purposely reduced. Test figures give 129° F. of superheat at boiler stop valves.
Factor of equivalent evaporation	1·259	1·229	1·238	1·242	1·242		
Equivalent evaporation from and at 212° Fahr. . . . lbs.	2·287	2·54	2·484	1·883	2·298	1·75 lbs.	
Average combustion chamber temperature . ° Fahr.	2,198	2,238	2,364	1,979	2,195	1600°–2200° F.	
Maximum ,, ,, ,, . ° Fahr.	2,653	2,593	2,850	2,250	2,587		
Minimum ,, ,, ,, . ° Fahr.	1,854	1,902	1,950	1,652	1,840		
Total weight of clinker produced . . lbs.	93,324	122,245	119,812	115,724	112,776	Total	
Percentage of clinker to total refuse burnt . per cent.	20·6	27·2	26·4	25·3	24·9		

The plant under test consisted of two of three units comprising the total installation. Each unit consists of one three-grate "Heenan" patent refuse destructor furnace, with a total grate area of 78 sq. ft.; one water tube boiler, with 1966 sq. ft. of heating surface; one Foster superheater; one regenerator or air heater; one Green's economiser with 960 sq. ft. of heating surface, and one 66 in. diameter low pressure "Heenan" centrifugal fan for supplying necessary air for combustion. The feed water was pumped from the hot well at electricity works to the destructor feed-water tank by a Worthington pump ($5\frac{1}{4} \times 6\frac{3}{4} \times 5$ in.), and before entering economisers passed through an open feed-water heater, utilising exhaust steam from the auxiliary steam engines. The feed water was supplied to the two boilers by one Weir pump, $6 \times 8\frac{1}{2} \times 12$ in.

Conditions of Test.—The above tests were carried out at four different periods of the year, in order to obtain the average results covering the whole year. Eaeh test was of four days' duration, and were, as far as possible, carried out under similar conditions. The steam generated was supplied to the electricity generating station, excepting for small quantity used for destructor auxiliaries and engine driving clinker utilisation machinery, and in Tests Nos. 3 and 4 an approximately 10 H.P. pump on city water main.

The refuse was weighed on a Pooley's weighbridge. The water was measured by a Kennedy's water meter (calibrated). The combustion chamber temperatures were taken with a Fery radiation pyrometer twice, and calibrated by the Cambridge Scientific Instrument Co. during intervals between the test. Other temperatures were taken with Le Chatelier and Pitkin White thermo couples and mercury pressure and expansion thermometers. Samples of the flue gases were collected over lengthy periods of the tests and analysed with Orsatt apparatus. The readings were taken periodically at quarter and hourly intervals, as required.

I hereby certify that the above tests were carried out under my supervision, and that the particulars stated above are correct.

(Sgd.) J. E. SWINDLEHURST, M.Inst.C.E.,
City Engineer.

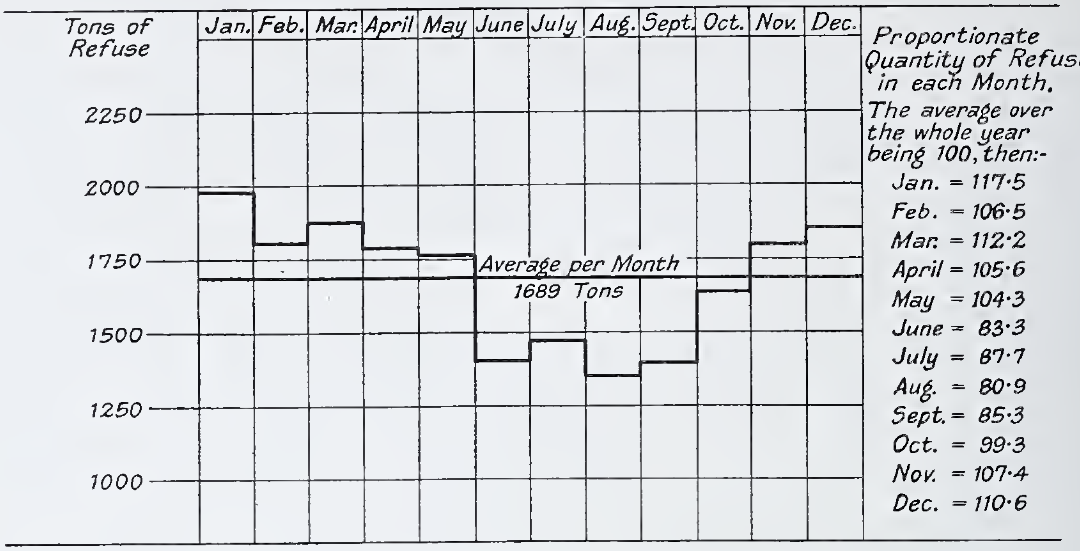


Fig. 42.—Diagram showing Proportionate Quantity of Refuse Burnt, Coventry Corporation Refuse Destructor.

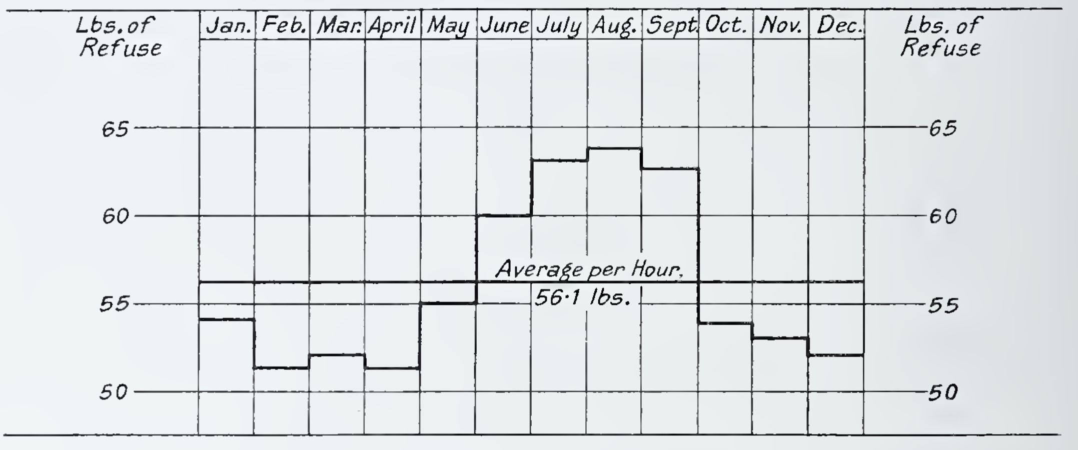


Fig. 43.—Diagram showing Average Rate of Burning per hour per sq. ft. of Grate Area.

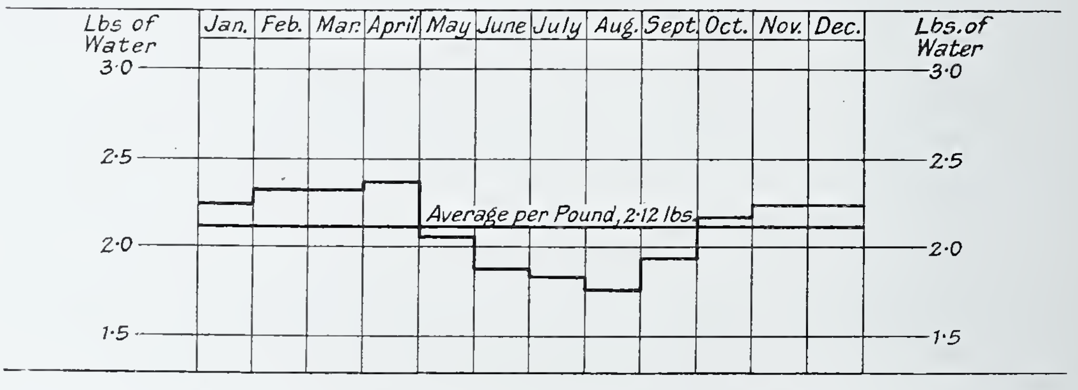


Fig. 44.—Diagram showing Average Evaporation per lb. of Refuse Burnt per month, based upon the Average for Three Years, equivalent from and at 212° F.

Borough Engineer of Preston, to whom the author is indebted for permission to include these records of three years' operation.

Upon reference to the diagram, Fig. 44, it will be observed that the average evaporation over a period of three years was 2·12 lbs. of water per lb. of refuse from and at 212° F. The maximum evaporation was 2·36 lbs. of water per lb. of refuse during the month of April, and corresponding with the lowest average rate of combustion. The minimum evaporation 1·74 lbs. of water per lb. of refuse was shown, as might be anticipated, during the month of August, corresponding with the highest average rate of combustion.

Mr Swindlehurst's figures show that a considerable range of fluctuation occurs as between the month of maximum results and the month of minimum results, these variations being as follows:—

Refuse available, to the extent of	45·2	per cent.
Rate of burning, ,, ,,	23·8	,,
Rate of evaporation, ,, ,,	35·6	,,

In a very complete and valuable paper [1] read before the Institution of Civil Engineers' Association of Birmingham Students, on 27th Feb. 1914, Mr Swindlehurst gave exhautive details of three years' operation of the Coventry plant and the supply of steam to the adjacent Corporation Electricity Works. The scope of this paper is so comprehensive that it may be said to be one of the most valuable contributions on operating results which has ever been prepared.

The following details [2] of a recent evaporative test of 100 hours' duration with a Heenan destructor at Guernsey are of more than ordinary interest, having in mind (1) the location of the plant, (2) its small size, and (3) the fact that it does not embody an air heater.

In the Channel Islands, relying entirely upon imported and expensive coal, it may be assumed that the calorific value of the refuse will be considerably lower than that of towns on the mainland, whether of a residential or industrial character.

Having in mind the quality of the refuse, and the use of air for combustion at atmospheric temperature, the small quantity of refuse dealt with, the character of the load, and the high exit temperature of the gases leaving the boiler, the results obtained must be regarded as exceptionally good.

The steam pressure and temperature diagrams reproduced in Figs. 45, 46, 47, and 48 are for a small plant unusually satisfactory. While it is not difficult with a large modern plant, using hot air for combustion, to show a reasonably even steam pressure, in this instance the average weight of refuse burned per hour was only ·66 tons. No doubt the comparatively small variation in steam pressure may to a large extent be accounted for by the use of mechanical clinkering.

[1] "The Construction and Working of a Modern Refuse Destructor," by J. Eric Swindlehurst, M.A. (Cantab.), A.M.I.C.E. The Institution of Civil Engineers' Association of Birmingham Students, 28th Session, 1913-14.

[2] For permission to publish these details the author is indebted to Mr Arthur G. Bird, Engineer and Manager of the Guernsey Railway Co., Ltd., and Messrs Heenan & Froude, Ltd., Worcester.

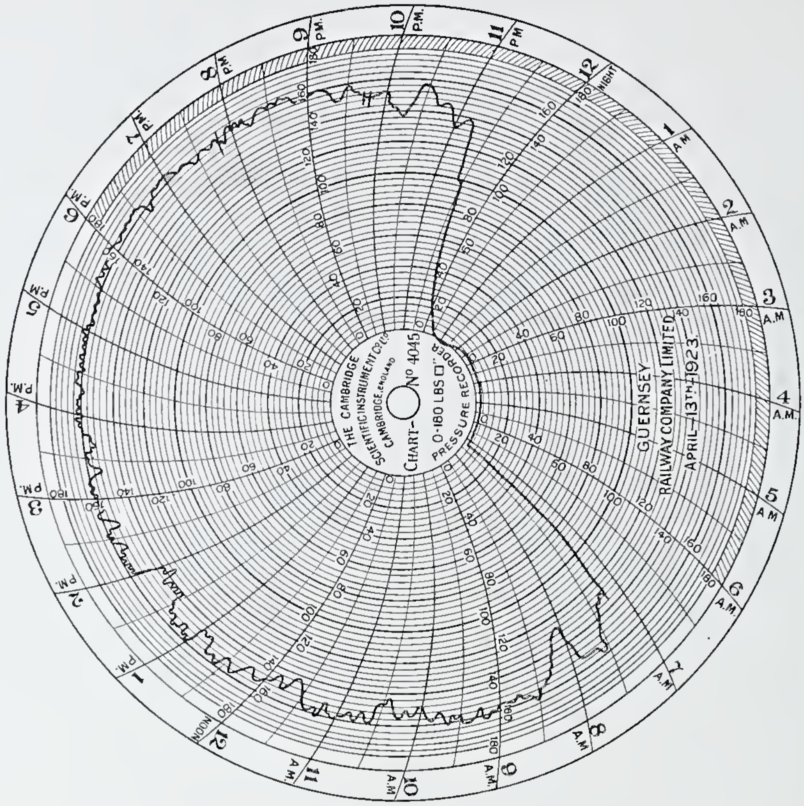


Fig. 46.—Steam Pressure Diagram, Heenan Back-fed Destructor. (Guernsey Railway Co., Ltd.)

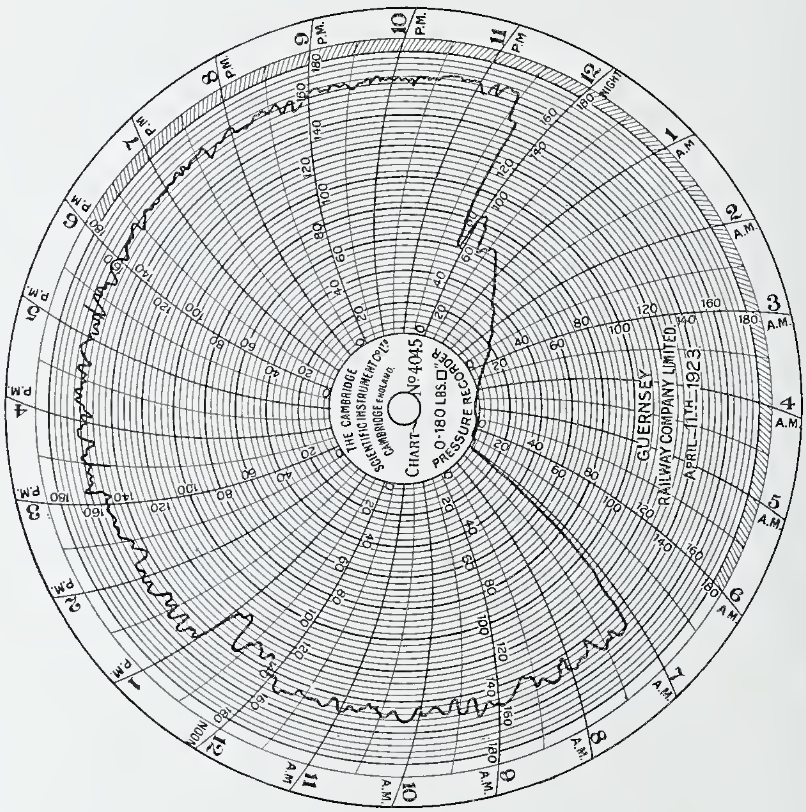


Fig. 45.—Steam Pressure Diagram, Heenan Back-fed Destructor. (Guernsey Railway Co., Ltd.)

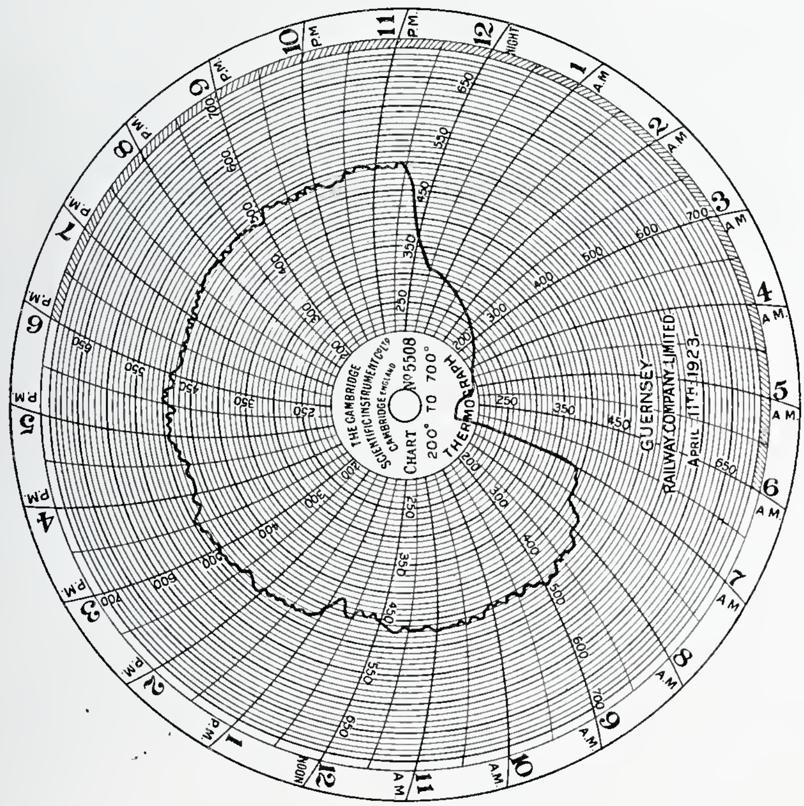


FIG. 47.—STEAM TEMPERATURE DIAGRAM, HEENAN BACK-FED DESTRUCTOR. (GUERNSEY RAILWAY CO., LTD.)

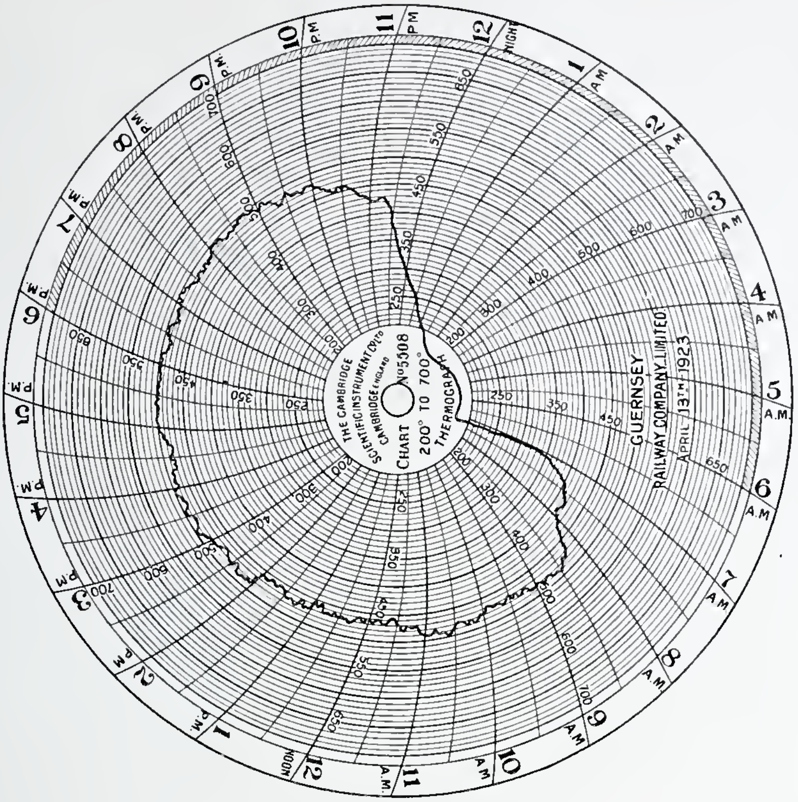


FIG. 48.—STEAM TEMPERATURE DIAGRAM, HEENAN BACK-FED DESTRUCTOR. (GUERNSEY RAILWAY CO., LTD.)

TABLE No. 32

Details of Evaporative Test. The Guernsey Railway Company, Ltd.

Log extracts of weekly run of power plant, comprising :—

Babcock & Wilcox boiler, heating surface 870 sq. ft.
,, ,, superheater.
Heenan & Froude 2-cell trough grate refuse destructor, with belt driven forced draught fan.
Generating set with condenser.

Note.—No coal or other supplementary fuel was used during this run, which was a normal ordinary weekly run.

Date	April 9th to 14th, 1923.
Duration	100 working hours.
Total refuse burned	66 tons=147,840 lbs.
Refuse burned per hour	1478 lbs.
Total water evaporated (by meter)	17,720 gallons=177,200 lbs.
Evaporation per pound of refuse, actual	1·198 lbs.
Steam pressure per sq. in.	150 ,,
Feed water temperature	135° F.
Temperature of superheated steam	470° F.
Superheat added to steam	104° F.
Factor of evaporation, including superheat	1·185
Equivalent evaporation per lb. of refuse from and at 212° F.	1·419 lbs.
Total electrical units generated	2920
Units generated per ton of refuse burned	44·2
Steam produced per unit generated, including large waste at safety valve	60·6 lbs.
Units used by belt driven fan per ton of refuse	4·54
Average load on generator	33 per cent.
,, ashpit pressure	2 in. W.G.
,, temperature of gases leaving boiler	600° F.

In Figs. 49 and 50 are shown respectively a view of the destructor cells at the clinkering floor, and also a view of the generating plant.

During the past twenty-five years approximately 250 refuse destructors have been erected in Great Britain and in many other countries, in connection with which more or less complete provision has been made for the utilisation of the available waste heat for steam generation.

The purposes for which the steam has been and is being used comprise electricity generation, sewage pumping, water pumping, gas works supply, heating

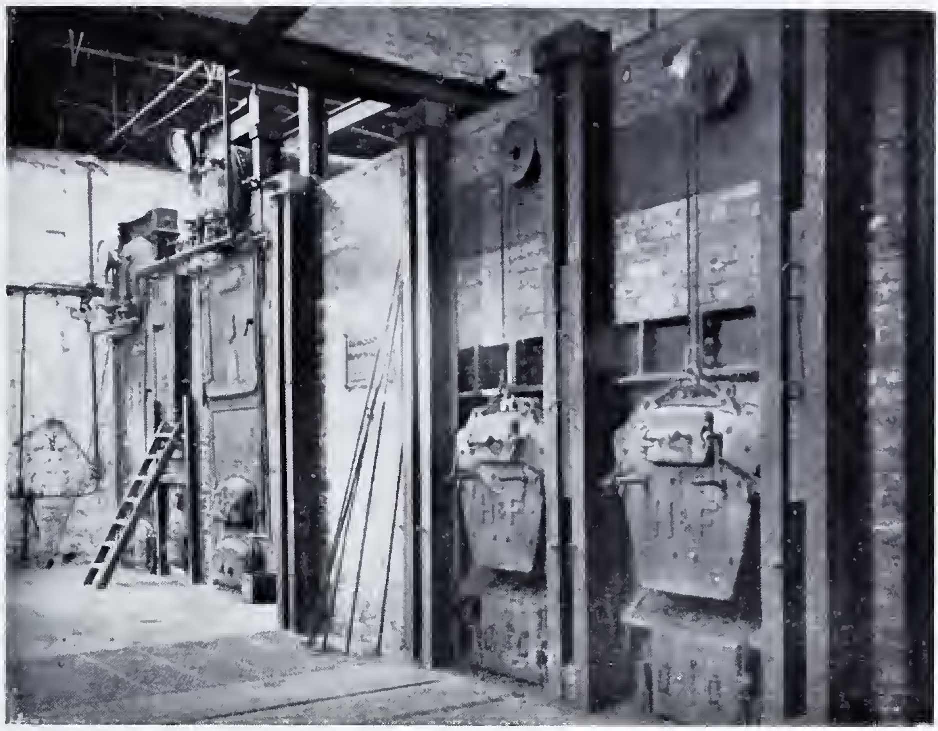


FIG. 49.—CLINKERING FLOOR, HEENAN BACK-FED DESTRUCTOR. (GUERNSEY RAILWAY CO., LTD.)

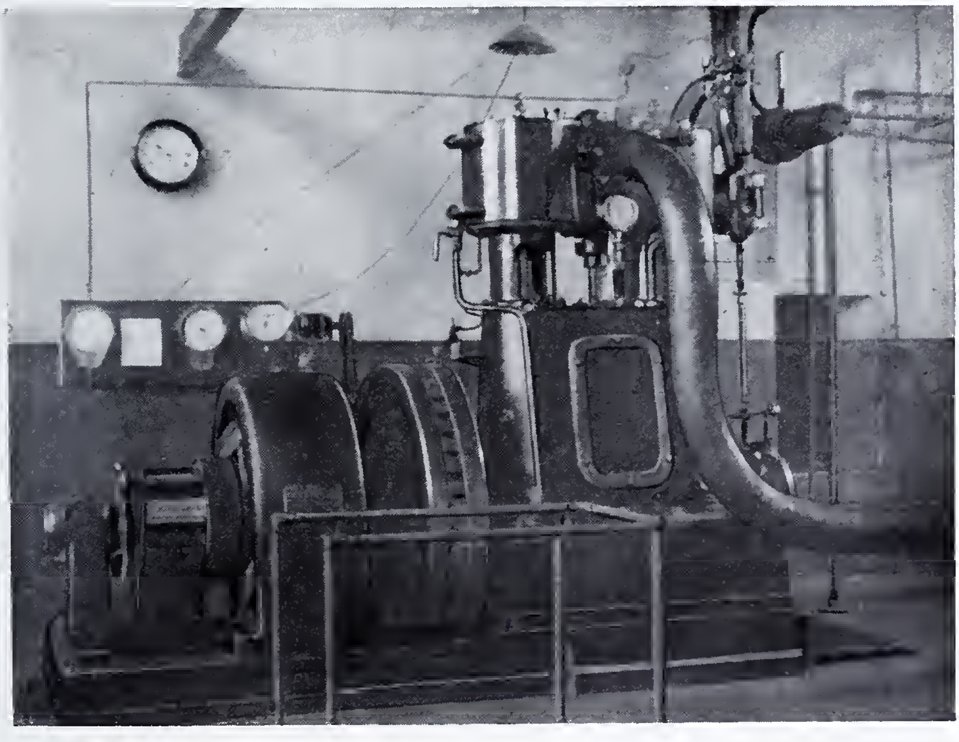


FIG. 50.—GENERATING PLANT. (GUERNSEY RAILWAY CO., LTD.)

plant, laundries, clinker utilisation plant, industrial works, and various municipal works.

That very large quantities of coal have been saved as the result of thus utilising waste heat is beyond question. In connection with upwards of 100 sewage pumping stations previously using steam coal in quantities varying from 300 tons to over 1000 tons per annum, the use of coal has either entirely ceased, or its use is restricted to Sundays and holidays, when there is no collection of refuse, although in some few cases, in order to meet exceptional pumping demands, it is necessary occasionally to put a coal fired boiler into service for short periods.

While, due to exceptional local conditions, there are cases where the pumping demand is so heavy as to be beyond the steam generation capacity of the refuse, such cases are comparatively few.

In the average case it has been shown that the available refuse is equal to providing the whole of the steam required for pumping the maximum flow of sewage, as also for the lighting of the works and clinker utilisation plant.

The combination of refuse destructors with electricity generating stations, which was so strongly advocated some twenty years since, has for various reasons failed to fulfil expectations as an ideal or even a satisfactory combination.

Generally speaking electrical engineers have not regarded the combination with any favour, it may, in fact, be observed that steam from refuse has rarely been desired unless it has been obtainable at a price considerably below its cost if generated from coal.

Having in mind that steam is the principal asset, in fact the only asset of importance in the combustion of refuse, its value under certain circumstances was regarded by those responsible for its production as at any rate approximately equivalent to steam generated by coal after making due allowance for the conditions and limitations of supply. It was, however, frequently found to be very difficult, even if not impossible, to get the purchasing department to take the same view.

The main disadvantages affecting the utility or value of the combination are (1) that it is desirable to operate the destructor continuously, and at a reasonably uniform rate, whereas its greatest value to an electricity undertaking in the saving of coal would be to burn refuse over a comparatively few hours, and with considerable flexibility in the rate of combustion. (2) In connection with the larger generating stations, even given the most favourable operating conditions, only a comparatively small and decreasing proportion of the total steam required could in any case be provided by the destructor.

The limited quantity of steam obtainable, as compared with the total requirements, the lack of flexibility, the fixed and limited time for collection and delivery, questions of storage, dust trouble, dual control, and actual as compared with assumed value, have all tended to discourage the more extended use of destructors in combination with electricity works.

It is doubtless due to these and other reasons that [1] the electrical output from

[1] Analyses and Summaries prepared by the Electricity Commissioners for the year ended March 31st, 1921.

refuse for the year ended March 31st, 1921, was only 17,613,330 units for thirty-four works, as compared with a total output of 4,955,514,403 units by 436 electricity works burning coal and coke.

One great advantage of the electricity works has been its comparatively central location with a consequent reduction in the cost of haulage. From every other point of view combination with a sewage pumping plant or some other municipal undertaking would appear to be preferable, as offering on the whole a much more favourable outlet for the steam available.

The all-important point is to make the most efficient use of the available waste heat and steam—in other words, if it is decided to burn refuse as a means of final and sanitary disposal—then it should be regarded as a low grade fuel, and the available heat should be utilised to the best possible advantage.

Even if this be done, it is only rarely and under exceptionally favourable conditions that a refuse destructor can be operated without incurring loss. If the available heat is wasted, then with no tangible asset to set against standing and operating charges, it is not possible to provide and operate a refuse destructor without incurring a loss, the extent of which will depend upon the standing and operating costs, and the value of the heat wasted from the point of view of its coal equivalent.

Despite its variable and unpromising composition as a fuel it has been possible when burning refuse under good conditions to obtain an evaporative output from boilers in excess of their rated capacity. The fuel value of refuse has been so conclusively demonstrated under such a variety of conditions during the past quarter of a century that to ignore this aspect, and to provide a refuse destructor merely to burn refuse, and to make no use of the available waste heat, might be regarded as unthinkable and impossible.

Far from this being the case, there are not a few installations where for many years past refuse in the aggregate equivalent to some hundreds of thousands of tons of coal per annum has been and still is being burned to waste. Such is municipal wisdom!

CHAPTER VII

BRIQUETTES AND BRIQUETTING

In a pamphlet dated 1603 Sir Hugh Platt referred to the manufacture at that time of a "compressed fuel," but such subsequent records as are available appear to show that briquettes were first manufactured about 1842 at Bérard, near St Etienne, France, followed by the first briquette works in England, at Newcastle-on-Tyne, in 1846.

Although the present annual production of briquettes in Germany is greater than the aggregate production in all other countries, it was not until 1861 that briquettes were first manufactured in Germany at Mulheim-on-Ruhr.

While it is true that the great bulk of briquettes made in Germany are manufactured from brown coal, as already discussed in a preceding chapter, this important development serves to demonstrate the great value and utility of briquetting, in enabling a fuel to be manufactured from raw coal, which in its original condition, and before treatment, could not be utilised for the same or similar purposes. For precisely similar reasons there is urgent need, from the point of view of conservation, for a considerable expansion of the briquetting industry in Great Britain.

In the Final Report of the Royal Commission on Coal Supplies, 1903–1905, briquetting is thus referred to :—

"Hitherto this industry has been mainly confined to South Wales,[1] where the small coal made in the screening, and in the transit of the best steam coal, is mixed with 8 per cent. to 10 per cent. of pitch, and converted into briquettes. Large quantities of similar small coal are exported to the continent for the same purpose.

Of the value of these briquettes as a fuel there is no doubt, and they are extensively purchased by the Navy as a reserve stock in hot climates, where they are said to deteriorate less than Welsh coal. In England and Scotland briquettes are seldom made, probably because there is a good market for small coal. There is, however, every reason to anticipate that in the future they will be more largely used for steam and domestic purposes, and there appears to be a good field for the discovery of a suitable binding material, pitch, which is the chief binder used at present, being rather too smoky for domestic purposes, and also high in price.

The evidence points to the conclusion that a suitable briquette plant, if well

[1] Final Report of the Royal Commission on Coal Supplies, Part 1, General Report, 1905.

managed, should pay in connection with a colliery ; at present the briquette factories in this country are mostly at or near docks. Suggestions have been made that partial distillation in addition to washing and cleaning would give a much wider choice of material for the manufacture of first class briquettes, and that coal and oil might be used in combination, so as to form briquettes of good calorific value out of inferior coal.

The evidence shows that seams which cannot now be worked at a profit will in future be rendered profitable, by washing, sorting, coking and briquetting the coal or converting it into gas, and that no small coal need be left in the mine.

It has been proved that large quantities of the best Welsh steam coal are left underground in the form of "small," solely because under present conditions it does not pay to bring it out. It appears that much of this "small," although it is frequently dirty, is of similar quality to that now being made into briquettes in South Wales, and we look to washing and briquetting as one of the available methods by which such coal can be brought out and used to advantage.

The annual production of patent fuel at this time (1905) was as follows :—

	England.	Wales.	Scotland.	Ireland.	Total exported.	Total available for home consumption.
Tons .	109,702	1,063,240	32,046	14,598	1,108,455	111,131

From 1905 to 1916 there was a steady increase in production, which was most marked in South Wales and Scotland. In England the annual production only increased to the extent of 20,000 tons, against increases of 571,000 tons in South Wales and 51,000 tons in Scotland.

Since 1916 the abnormal price of pitch has not only seriously retarded development, but has created a position of great difficulty for the briquetting industry, during a period when under normal conditions there would have been very considerable expansion.

In the Final Report of the Coal Conservation Committee, 1918, after referring to the Report of the Royal Commission on Coal Supplies, 1903–1905, and discussing the present position, the following conclusion is expressed :—" But we are of opinion that a more determined effort should be made to encourage the consumption of patent fuel in the United Kingdom, both for steam raising and domestic purposes, thereby achieving two objects :—

" (1) Inducing colliery owners to bring to bank more of the small coal, and

" (2) Setting free for export a greater quantity of large coal, which, by reason of its higher price, is better able to bear heavy freights, and meet German and American competition in oversea markets."

Having in mind the very large quantities of fuel suitable for briquetting which have been and still are available in Great Britain, it is a matter for regret that

the development of the briquetting industry has been so slow and the output so small.

For reasons which are to some extent obscure, "manufactured fuel" has been regarded with some suspicion, and despite its general convenience and cleanliness, due to the freedom from small coal and dust, it has to a serious extent failed to appeal to consumers in this country, with the result that the great bulk of the production of patent fuel has been, and still is, exported. The following comparative figures,[1] covering the tonnage manufactured, exported, and consumed at home, have been extracted from the Final Report of the Mining Sub-Committee—Coal Conservation Committee, Final Report, 1918 :—

Patent Fuel

Year.	Total manufacture.	Exported.	Available for home consumption.
	Tons.	Tons.	Tons.
1905	1,219,586	1,108,455	111,131
1906	1,513,220	1,377,209	136,110
1907 [2]	1,670,000	1,480,493	189,107
1908	1,604,649	1,440,438	164,211
1909	1,511,645	1,455,842	55,803
1910	1,607,666	1,470,491	136,875
1911	1,779,133	1,612,741	166,392
1912	1,755,869	1,580,803	175,066
1913	2,213,205	2,053,187	160,018
1914	1,840,465	1,607,757	232,708
1915	1,697,451	1,225,071	472,470
1916	1,854,573	1,324,695	529,878

These figures clearly show that under normal conditions, and with the exception of the last three years, the tonnage of patent fuel consumed in this country was very small. During the last three years referred to above the increased home consumption was doubtless due to the then existing stringent fuel conditions, and the limitation of exports, as the result of the war.

While South Wales briquettes have been extensively used in France, the following figures, showing the principal exports from South Wales and Monmouthshire for the year 1919, indicate a wide distribution :—

	Tons.
Denmark	2,239
German West Africa	2,479
Netherlands	4,157
Belgium	4,060
France	1,068,328

[1] Final Report on Mining Sub-Committee, Appendix 11, page 70. Coal Conservation Committee, Final Report, 1918.

[2] Figures compiled by the Census Production Office.

	Tons.
Algeria	107,625
French West Africa	23,689
Switzerland	15,595
Spain	59,453
Italy	152,467
Austria-Hungary	12,649
Tunis	15,373
Morocco	34,722
Peru	13,164
Chili	11,000
Brazil	36,604
Uruguay	26,336
Argentine Republic	42,555
Egypt	4,725
British Guiana	2,350

The total tonnage exported was 1,646,343, which, if compared with the figures previously quoted, shows that this was not an abnormal year from the point of view of the total quantity exported.

It may be observed, why is this fuel, the base of which is small coal of good quality, favoured abroad, while in Great Britain there has been but little or no demand for manufactured fuel ?

To a large extent the explanation may be found in the fact that there has been a sorry lack of enterprise upon the part of briquette manufacturers. No really effective steps have been taken to educate consumers, either industrial or domestic. It is mainly for this reason that manufactured fuel has been and still is erroneously regarded as at the best a poor or doubtful substitute for raw coal, whereas actually briquettes may be made in such convenient shapes and of such composition as to provide both for industrial and domestic consumption fuels which are at least equal to, and probably better than, a large proportion of the raw coal used, from the point of view of unvarying calorific value and low ash content.

Not only is the present position due to failure upon the part of briquette manufacturers to educate consumers, it may also to some extent be attributed to the fact that briquettes have been made and sold mainly for domestic use, of unsatisfactory sizes and shapes, and containing an excessive proportion of incombustible.

According to the latest available report of H.M. Chief Inspector of Mines (for 1921), the total production of briquettes in Great Britain and Ireland during that year was 1,064,000 tons, or rather less than the tonnage exported to France during 1919.

While no more recent figures are available, it may be assumed that the present rate of production is probably less than in 1921, this being due entirely to the scarcity of coal tar pitch and its abnormal price.

In spite of exhaustive experiments in this country and in other countries with a view to the discovery of an economic and efficient binding medium as a substitute for pitch, no really satisfactory substitute has yet been discovered, and the only effective agglomerant which has been generally used is pitch. Although briquettes were made in France about ninety years since, using smudge and coal tar, pitch has been constantly used since 1842, the particular grade which is favoured for briquetting being known as medium soft coal tar pitch.

In the endeavour to discover an efficient and commercially practicable substitute for pitch as a binding medium, very exhaustive experiments have been made with a considerable variety of materials, both organic and inorganic, comprising, among others, clay, lime, cements, wood tars and resin, wood pulp and sulphite liquor, beet pulp, molasses, starch, various tars and pitches, from coal, natural asphaltes and petroleum products.

Inorganic binders possess one very serious disadvantage, inasmuch as they increase the incombustible content of the fuel ; a further objection is that the briquettes are weak, and will only harden slowly. As inorganic binders are not volatile, when once the briquettes are hard, they do not readily disintegrate in the fire.

Clay, the commonest and most readily available of the inorganic materials, cannot be regarded as a satisfactory binding medium, although it has been used for many years past in South Wales in the preparation of a plastic mixture of anthracite duff for domestic use which is known locally as "Péle." This mixture is usually hand moulded by the consumer and is used in the shape of balls.

While such a fuel is obviously unsuitable and useless for starting a fire, it is used in replenishing, and as a cheap domestic fuel it appears to give satisfaction in a district where the use of anthracite is general.

Among the various organic materials which have been tried, some have given promising results, but in almost every case without exception it has not been commercially practicable to carry production beyond the laboratory stage, and an efficient substitute for pitch has yet to be discovered.

From 1904 to 1912 a very exhaustive series of experiments in briquetting were made under the supervision of the United States Geological Survey at the fuel testing plants of St Louis, Mo., and Norfolk, Va. During the series of tests the binding properties of a considerable number of materials were closely investigated. Some of the results obtained with various binders are shown in the following table :—

TABLE No. 33

Summary of Results of Laboratory Briquetting Tests of various Fuels and Binders [1]

Fuel.	Binder.	Smallest percentage which made a satisfactory briquette.	Crushing strength of briquette made with minimum of binder, lbs. per sq. in.	Crushing strength of briquette made with 6 per cent. binder, lbs. per sq. in.	Weather-resisting qualities of 6 per cent. briquette.
Pittsburgh slack	Water gas pitch	(*a*) 6·0	2220	2220	Excellent
,, ,,	Corn starch	3·0	2100	N.D.	Fair
,, ,,	Hard wood tar pitch	4·0	1950	2275	Good
,, ,,	Cell pitch	2·0	1800	3800	Poor
,, ,,	Sulphite liquor	3·0	1400	1875	Very poor
Texas lignite	Water gas pitch	6·0	800	800	Good
,, ,,	Wheat flour	3·0	900	1375	Fair
,, ,,	Cell pitch	(*a*) 8·0	1250	. .	Poor
,, ,,	Sulphite liquor	(*b*) 9·0	725	525	Very poor
Pennsylvania anthracite culm	Cell pitch	3·0	2700	. .	Poor
,, ,,	Sulphite liquor	5·0	2500	. .	Very poor
North Dakota lignite	Water gas pitch	(*b*) 8·0	650	300	Fair
,, ,,	Wheat flour	3·0	750	1125	Fair
,, ,,	Cell pitch	8·0	925	550	Poor
,, ,,	Water gas pitch	(*b*) 8·0	350	400	Fair
,, ,,	Wheat flour	5·0	1125	1200	Fair
,, ,,	Sulphite liquor	(*b*) 9·0	300	. .	Very poor
Phillipine lignite	Water gas pitch	6·0	1400	1400	Good
,, ,,	Wheat flour	4·0	1550	1550	Fair
,, ,,	Corn starch	(*b*) 5·0	1225	. .	Fair
,, ,,	Cell pitch	6·0	925	925	Poor
,, ,,	Sulphite liquor	(*b*) 8·0	725	600	Very poor
Utah sub-bituminous	Water gas pitch	7·0	1050	. .	Good
,, ,,	Cell pitch	4·0	1150	. .	Poor
Washington sub-bituminous	Water gas pitch	6·0	1200	1200	Good
,, ,,	Wheat flour	(*a*) 5·0	1500	. .	Fair
,, ,,	Corn starch	(*a*) 5·0	1850	. .	Fair
,, ,,	Cell pitch	6·0	1000	1000	Poor

(*a*) Lowest percentage used in tests, but not necessarily the lowest that would furnish a satisfactory briquette.

(*b*) This percentage was not sufficient to make entirely satisfactory briquettes, but was the highest used in the tests.

The essential qualities in a binder are thus summarised by Mr James E. Mills, in Bulletin No. 343 of the United States Geological Survey :—

(1) It must be sufficiently cheap to make the manufacture of briquettes profitable.

[1] "Fuel Briquetting Investigations," July 1904 to July 1912, by C. L. Wright, Bulletin No. 58, Department of the Interior Bureau of Mines, U.S.A., 1913.

(2) It must bind strongly, producing a briquette sufficiently hard but not too brittle.
(3) It must hold the briquette together satisfactorily in the fire.
(4) It must produce a briquette sufficiently waterproof to stand the conditions of use.
(5) It should not cause smoke or foul smelling or corrosive gases or foul the flues.
(6) It should not increase the percentage of ash or clinker.
(7) It should increase, or certainly not diminish, the heat units obtainable from a given weight of fuel.

Normally the whole of the requirements as set forth above have been fulfilled by pitch, and it may be observed that no other agglomerant has yet been discovered which so completely and satisfactorily meets the required conditions.

One very important requirement in connection with briquettes is cohesive strength, for which it has been usual to accept the French standard test as a standard. This test for cohesion may be briefly described as follows :—

One hundred briquettes each weighing 1·1 lbs. are placed in a cylinder 36·22 in. in diameter and 39·37 in. in length which is divided into three compartments, and revolves at a speed of 25 revolutions per minute. After having been charged the cylinder is revolved for two minutes. The contents are then sifted upon a screen perforated with openings 1·12 in. square. That proportion which remains upon the screen indicates the cohesive strength, which in the case of the French Admiralty tests should be from 52 per cent. to 58 per cent.

Briquettes of any desired degree of cohesion may be made by varying the proportion of binding material and the pressure. This is illustrated by the experiments made by Wéry [1] of Paris with a Bietrix machine, which gave the following results :—

Pressure in kilogrammes per square centimetre.	Pressure in lbs. per square inch.	Pitch used (percentage).	Cohesion obtained (percentage).
130	1844	6	25
190	2695	6	46
270	3831	6	61
130	1844	7	52
190	2695	7	70
250	3547	7	74

In Great Britain, to a large extent, the production of briquettes or patent fuel has been confined to South Wales. Both in England and in Scotland, mainly in colliery areas, a number of works have been erected, but compared with the production in South Wales, the output has been small. The present potential output from works in South Wales will probably be not less than 5 million tons per annum, or rather more than one-eighth of the total production in all countries.

[1] "Briquettes as Fuel," Special Consular Report, U.S.A., No. 26, 1903, page 54.

Prominent among the South Wales works are the following :—

Makers.	Brand.	Sizes of Briquettes made.	Weights of Briquettes.
The Crown Preserved Coal Co., Ltd.	Crown	$10'' \times 8'' \times 6\frac{1}{2}''$	$24\frac{1}{2}$ lbs.
” ” ”	”	$8\frac{1}{4}'' \times 6\frac{1}{4}'' \times 5\frac{1}{2}''$	$12\frac{1}{2}$ ”
The Star Patent Fuel Co. . .	Star	$10{\cdot}8'' \times 6{\cdot}8'' \times 7{\cdot}4''$	$22\frac{1}{2}$ ”
Messrs L. Gueret, Ltd. . .	Anchor	$12'' \times 8\frac{1}{2}'' \times 5\frac{1}{2}''$	26 ”
” ” ”	”	$10'' \times 6\frac{1}{2}'' \times 4\frac{1}{2}''$	12 ”
The Atlantic Patent Fuel Co., Ltd.	Atlantic	$9'' \times 5\frac{1}{2}'' \times 4''$	10 ”
The Graigola Patent Fuel Co., Ltd.	Graigola,[1] Merthyr	$9\frac{1}{2}'' \times 5\frac{1}{2}'' \times 4''$	9 ”
The Pacific Patent Fuel Co., Ltd. .	Pacific	$9\frac{3}{4}'' \times 5\frac{7}{8}'' \times 4''$	10 ”
The Phœnix Patent Fuel Co., Ltd.	Phœnix	$12'' \times 9'' \times 4\frac{7}{8}''$	23 ”
The Cardiff and Newport Patent Fuel Co., Ltd. . . .	Arrow	$10'' \times 6\frac{3}{4}'' \times 5\frac{1}{2}''$	15 ”
The Cardiff Smokeless Fuel Co., Ltd.	Castle	$10'' \times 7\frac{1}{4}'' \times 4\frac{1}{2}''$	16 ”
” ” ” ”	”	$10'' \times 5\frac{1}{2}'' \times 4''$	11 ”
” ” ” ”	”	$9'' \times 5'' \times 3''$	$6\frac{1}{2}$ ”
The Rose Fuel Co., Ltd. . .	Rose	$11\frac{5}{8}'' \times 9\frac{1}{16}'' \times 5\frac{5}{8}''$	26 ”
” ” ”	”	$9\frac{3}{16}'' \times 5\frac{9}{16}'' \times 4\frac{9}{16}''$	11 ”
The Reliance Fuel Co., Ltd. .	”	$11\frac{5}{8}'' \times 8\frac{3}{4}'' \times 4\frac{5}{8}''$	$22\frac{1}{2}$ ”

Fig. 51.—Selection of Briquettes of Varied Shapes and Sizes.

[1] For locomotives.

The sizes and weights given above are typical of the block briquettes made; in addition to this type Ovoid briquettes have also been made in various sizes, and there is no doubt that the demand for this useful shape is bound to increase.

Fig. 51 illustrates a selection of briquettes of various shapes and sizes, the rectangular briquettes weighing from 24 lbs. to 2 lbs. each, and the Ovoids from 5 ozs. to $1\frac{1}{4}$ ozs. The most convenient shape of briquette, both for domestic and general industrial use, is the Ovoid, which is made in a number of sizes, varying in weight from $1\frac{1}{4}$ ozs. to 6 ozs.

Owing to their shape Ovoid briquettes, whether used in an ordinary open domestic grate or on the horizontal grate of a steam boiler, provide a sufficiency of air space to ensure active combustion.

In Fig. 52 is shown a perforated Ovoid briquette introduced by the Perforated Fuel Syndicate, Ltd. This type of Ovoid, which is used both in France and Germany, possesses obvious advantages in facilitating ignition and combustion, and quickly produces a hot and clear fire. Perforated Ovoids, made from anthracite duff, can not only be used for all purposes for which anthracite nuts are employed, but may also be used in an open grate.

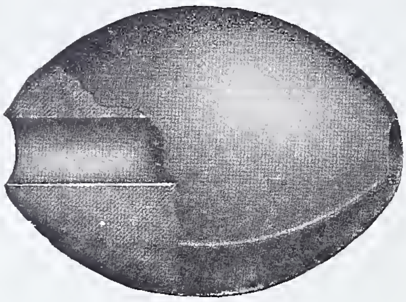


Fig. 52.—Perforated Ovoid Briquette.

Among the larger briquette works in South Wales are those of The Graigola Patent Fuel Co., Ltd., having a capacity of over one million tons per annum; The Crown Preserved Coal Co., Ltd., with an annual output of from 500,000 to 600,000 tons; The Phœnix Patent Fuel Co., Ltd., 325,000 tons; and The Rose Patent Fuel Co., Ltd., which works will be subsequently described, having a present capacity of 750,000 tons.

Analyses of Graigola and Phœnix briquettes by Mr Llewellyn J. Davies, F.C.S., gave the following results:—

	Fixed carbon.	Volatile matter.	Ash.	Moisture.
Graigola (Locomotive) .	71·0	15·50	10·0	1·50
Phœnix	73·25	17·0	8·50	1·25

Rose patent fuel is made to suit any specified requirement within a range of from 17 to 22 per cent. of volatile content, and 5 to 10 per cent. of ash, while the agreed calorific value standard is guaranteed.

The following are analyses of various makes of briquettes:—

Rose Patent Fuel.	As Fired.	Dry.
Moisture	2·00 per cent.	. .
Carbon	81·24 ,,	82·90 per cent.
Hydrogen	4·13 ,,	4·22 ,,
Oxygen and Nitrogen . . .	3·71 ,,	3·78 ,,
Combustible Sulphur . . .	·59 ,,	·60 ,,
Ash	8·33 ,,	8·50 ,,

Proximate Analysis

Moisture	2·00 per cent.	. .
Volatile matter	20·60 ,,	21·0 per cent.
Fixed carbonaceous matter	69·07 ,,	70·5 ,,
Ash	8·33 ,,	8·5 ,,
Calories	7,865	8,026 per kilo.
British Thermal Units	14,157	14,447 per lb.
Equivalent to lbs. of water evaporated per lb. of fuel burned from and at 212° F.	14·60	14·89

	Reliance Steam Briquette.[1]	Reliance Anthracite Ovoid.[1]
Fixed carbon	72·06 per cent.	74·88 per cent.
Volatile matter	16·45 ,,	12·17 ,,
Ash	9·75 ,,	8·59 ,,
Moisture	1·74 ,,	4·36 ,,

Evans & Rogers, Swansea, Blended Ovoids, 4½ ozs. and 1½ ozs.

	Carbon.	Ash.	Volatile Content.
Household	75 per cent.	7 per cent.	18 per cent.
Central heating	81 ,,	7 ,,	12 ,,
Steam generation	78 ,,	7 ,,	15 ,,
Anthracite	83 ,,	7 ,,	10 ,,

Sun Eggettes (The Sun Fuel Co., Ltd., Swansea)

	Domestic.	Steam.
Volatile matter	10–12 per cent.	14–16 per cent.
Ash	7–9 ,,	8–10 ,,
Calories	7300–7600	8000–8100

Polmaise[2] (Stirling) Briquettes, 9 in. × 6 in. × 5¼ in. = 12 lbs. each for Steam and Navigation

Moisture	4·20 per cent.
Ash	8·10 ,,
Volatile matter	15·98 ,,
Coke	79·82 ,,
Sulphur	·57 ,,
Calories	7,680 ,,
British Thermal Units	13,824 ,,

[1] Analyses by Mr Llewellyn J. Davies, F.C.S., Cardiff.
[2] Analysis by Glasgow City Analysts and Gas Examiners Laboratory.

Manor Powis[1] *(Stirling) Rectangular and Ovoid Briquettes*

Fixed carbon	70·48 per cent.
Volatile matter	16·40 ,,
Moisture	6·00 ,,
Ash	7·12 ,,
	100·00 ,,

Coke Breeze, Ovoid Briquettes. (Smethwick Corporation Gas-works)

	As Received.	As Dried.
Volatile matter	10·99 per cent.	11·59 per cent.
Coke	83·82 ,,	88·41 ,,
Ash	16·19 ,,	17·08 ,,
Fixed carbon	67·63 ,,	71·33 ,,
Hygroscopic moisture	5·19 ,,	. . .
Calorific value, B.T.U.'s	10,850 ,,	11,816 ,,
Carbon equivalent	. . ,,	12,065 ,,
Evaporative power, lbs. of water per lb. of fuel from and at 212° F.	11·23 ,,	12·24 ,,

As a general rule it is not desirable to manufacture briquettes having an ash content exceeding 10 per cent. Although this would appear to preclude the use of low grade or waste fuels, actually this is not so, because by blending or washing, or both, the ash content may without difficulty be kept within the above limit.

For the production of the better qualities of briquettes washing is now regarded as essential. In the briquetting of coke breeze, which has been regarded merely as a means of utilising breeze dust and very fine breeze, it has not been customary to wash the fuel. To some extent this will account for the lack of success.

While it has been the practice, in connection with certain well-known brands of briquettes made for particular requirements, to closely conform to specifications as to composition, ash content and calorific value, it would appear that the possibilities of blending, in ensuring a given volatile and ash content and a fixed calorific value, have not yet been fully realised.

Further, as already observed, it has been alleged that briquettes have been manufactured and sold for domestic use not only unsuitable in shape and size, but containing an excessive proportion of incombustible, with the inevitable result that fuel in this form has been regarded as a very unsatisfactory substitute for ordinary household coal.

In the more recent briquetting practice, which will be subsequently discussed, a special feature has been made of the mixing and blending of carefully selected fuels, with a view to the production and sale of a manufactured fuel which will

[1] Analysis by W. H. Herdsman, Chemical Laboratory, Glasgow.

constantly comply with an agreed standard specification, the makers guaranteeing a standard calorific value, volatile content and ash percentage.

This marks a distinct and valuable advance in briquetting practice, inasmuch as a manufactured fuel is thus offered upon a basis which for all practical purposes does not yet obtain in connection with the sale of raw coal.

The use of fuel which rigidly conforms to a standard specification as to its composition and calorific value should widely appeal both to industrial and domestic users, while at the same time being an effective means of conservation by the extended use of a considerable range of small fuels which are at present to a large extent neglected and unused, mainly because of their size presenting difficulties in their utilisation in the raw state.

In the manufacture of Ovoid briquettes for domestic use, while having due regard for the percentage of ash, it would appear that insufficient attention has been given to the composition of the ash. By the careful blending of fuels not only is it possible to reduce the ash content, but it should not be difficult to render the ash fusible at a *lower* temperature, thus yielding a solid ash or clinker instead of a very light and powdery ash, which for domestic use is most objectionable.

In the production of briquettes for industrial use the selection and blending of fuels should be such as to ensure the fusion of ash at a high temperature. Ash which is fusible at too low a temperature is very troublesome in steam generation, in the rapid production of clinker, and the subsequent choking of the fire.

While as the result of the closer attention which has been directed to the selection of small fuels and washing the percentage of ash has been materially reduced, it would appear that the important question of fusion temperature has not yet received the attention which it demands.

It is important that all coal containing upwards of 3 per cent. of moisture should be dried, the cost of drying is more than compensated for by the reduced percentage of binding material necessary, in addition to which it is not possible to manufacture satisfactory briquettes from coal containing a high moisture percentage.

Accurate measuring and complete mixing are of the utmost importance, and in order to ensure absolute uniformity in the composition of the finished briquette the work should be done by an automatic machine.

The importance of automatic measuring is now generally conceded. Before this system was used it was necessary to stop the plant while adjustments were made to the measuring apparatus in order to vary the proportion of binder to the coal. By the use of revolving table measuring apparatus the necessary adjustments may be made while the plant is running, by the alteration of the angle of the scraper, or by the raising or lowering of the sleeve attached to the service hopper. When briquettes are being made to a specification requiring the admixture of two, three or four grades of small coal, revolving table measurers are of great advantage, as the ash content and calorific value may be varied at will.

In moulding and pressing plant the essential features are ample strength and reliability under regular running conditions, with a low maintenance cost. The

earlier presses were much too light in construction, involving unreliability in operation and heavy maintenance cost. Having in mind that the pressure required varies from two tons to three tons per square inch, adequate strength is essential.

In the manufacture of the larger briquettes weighing from 8 lbs. to 26 lbs. double compression, *i.e.* equal and simultaneous pressure both on the top and the bottom of the briquette, is essential in order to obtain uniformity of structure. For smaller blocks, from 2 lbs. to 4 lbs. weight, a heavy single pressure machine may be used, but such a press is only suitable for a small output.

Heaters should be of ample size for a given duty, in order to ensure the highest efficiency from the proportion of binder used.

When the mixture leaves the heater it is important that it should be cooled to a suitable temperature before being fed to the press, this results in fewer breakages

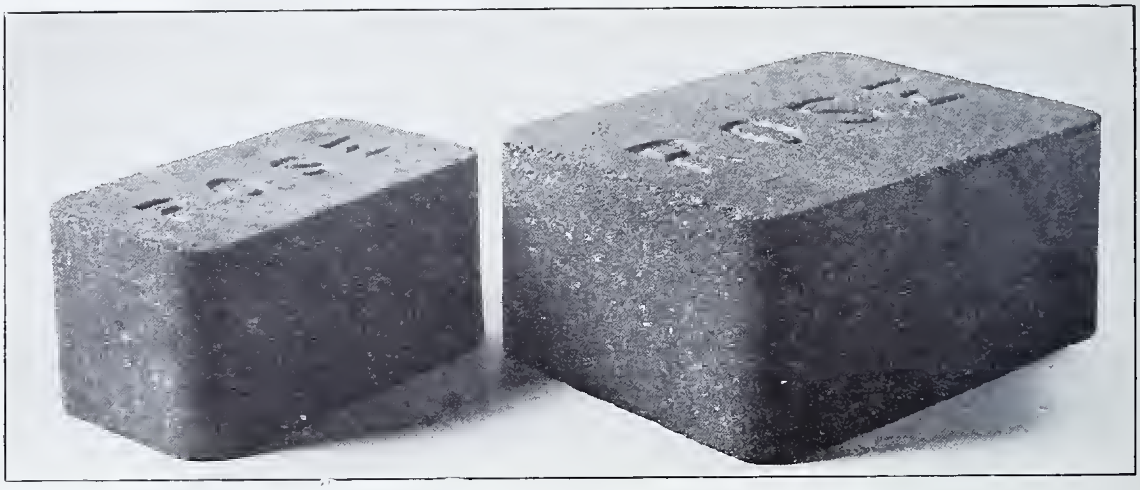


Fig. 53.—" Rose " Patent Fuel.

after the briquettes leave the press, as also a better finish. With Ovoid briquettes this is specially desirable.

For the cooling of the briquettes as they leave the press slow-moving conveyors are generally employed: these may in the case of Ovoids be used for automatic loading. The cooling conveyor greatly reduces the waste due to breakage, and also prevents subsequent " sweating " of the fuel.

Among the largest and most modern briquetting works in South Wales is that of The Rose Patent Fuel Company, Ltd., Swansea, which has already been referred to. The initial capacity of the works was 750,000 tons per annum, and when the second unit is completed the total capacity will be $1\frac{1}{2}$ million tons per annum.

Two sizes of blocks are made as illustrated in Fig. 53, these being respectively $11\frac{5}{8}$ in. × $9\frac{1}{16}$ in. × $5\frac{5}{8}$ in., weighing 26 lbs., and $9\frac{13}{16}$ in. × $5\frac{9}{16}$ in. × $4\frac{9}{16}$ in., weighing 11 lbs. The composition of the fuel is varied to suit any specified requirement within certain limits, these being approximately a range in volatile content of from 17 to 22 per cent., and ash content of from 5 to 10 per cent., the calorific

standard being guaranteed. On this basis fuel is specially blended and made to comply with a specification, and to displace other fuel.

As a large, modern, and very completely equipped works, a description will doubtless be of interest. A general plan showing part of the site and illustrating the lay-out is shown in Fig. 54. The works and process may be divided into three main sections for convenience in describing the same: (1) coal cleaning, drying, reception, measuring, blending and granulating, also reception, measuring and

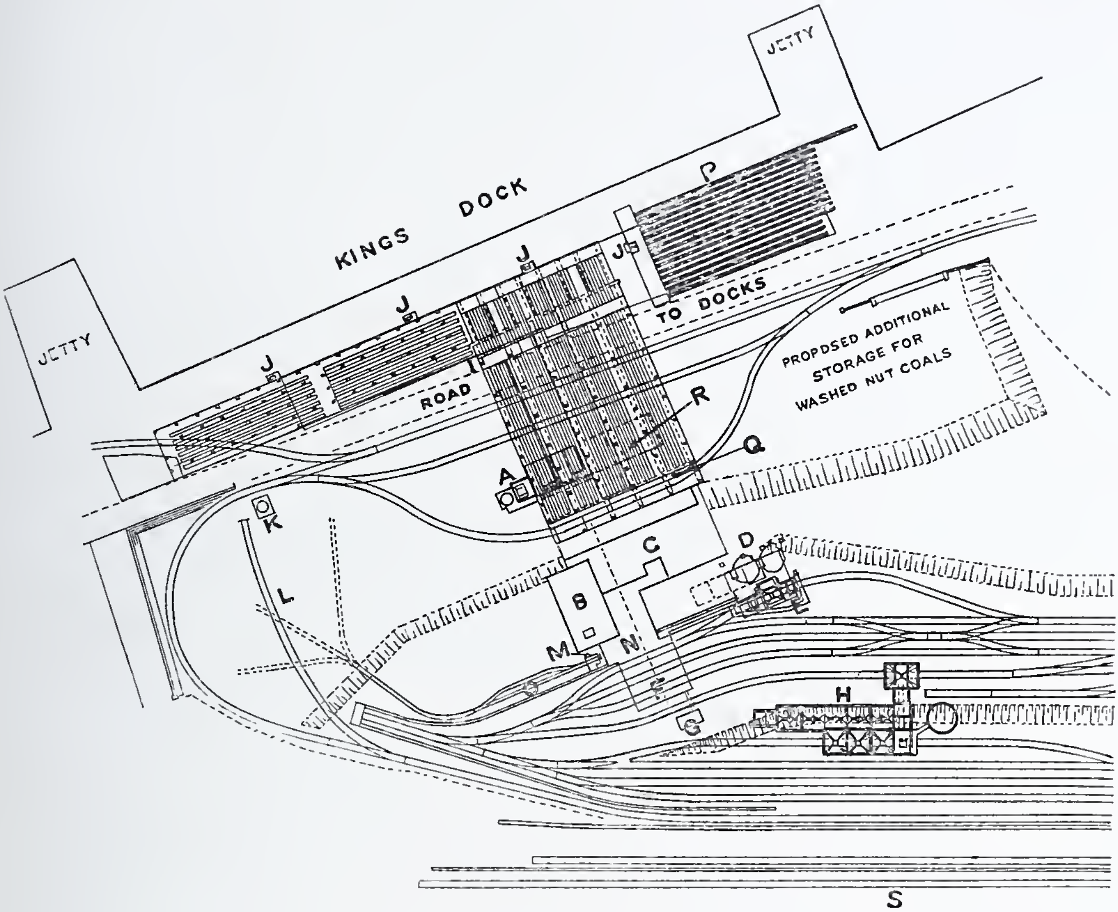


Fig. 54.—General Plan and Lay-out of Works, The Rose Patent Fuel Co., Ltd., Swansea.

A = Fan and pump house.
B = Engine-room, containing rotary convertor and switchboard.
C = Press house with line of presses.
D = Coal dryers.
E = Coal bin.
F = Main coal bins.
G = Oil tank.
H = Washery.
J = Auto-weighers.
K = Hydraulic accumulator.
L = Storage for pitch.
M = Pitch auto-weigher.
N = Preparation section.
O = Pitch road.
P = Stores (underneath).
Q = Traverser pit.
R = Boilers.
S = Sidings.

mixing of the binding ingredients; (2) distribution, heating, agglomerating, pressing and cooling; (3) steam and power equipment.

The incoming wagons with supplies are directed according to the class and condition of the coal, either to a washery or dryer reception bin, or to one or other of three main reception bins, all of which are constructed of reinforced concrete, and arranged below ground level. Over each of these bins extends an intake siding

for the particular class of coal, discharge of the wagon therein being effected by direct acting hydraulic tips, two of which are provided for each bin so that wagons may be tipped from either end. The wagons after being discharged pass automatically—by gravity—on to the low level sidings.

Coal Washery.—The coal is raised by a totally enclosed elevator to the upper part of the washery building, where the washing plant is located, the lower part of this building containing the bunkers both for the washed coal and the extracted shale.

The cleaning or washing process provides for the extraction of the ash-forming constituents of the coal, dirt, shale, etc., which material is elevated by two perforated bucket elevators to a bunker. The washed coal passes over drainage sieves and then to vibrating screens, where it is classified or graded in sizes $1\frac{3}{4}$ in. to $1\frac{1}{4}$ in., $1\frac{1}{4}$ in. to $\frac{1}{2}$ in., and if desired, $\frac{1}{2}$ in. to $\frac{1}{4}$ in., these being delivered by chutes direct to their respective bunkers. The " fines " pass over a concentrator on to vibrating screens where it is drained, and finally to a scraper conveyor above the storage bunkers for distribution thereto.

The washery provides for automatic and continuous recovery of the settled slurry from the circulating water, which is utilised by distribution among the washed " fines " for the works.

After draining, the " fines " with the concentrated slurry is withdrawn from the bunkers as required by means of a second scraper conveyor underneath. This conveyor transfers the fuel to an elevator, which in turn delivers it on to a band conveyor, whence it passes to the dryers.

Coal Drying.—After drainage in the washery bins the " fines " for fuel manufacture have a moisture content of approximately 10 to 12 per cent., which in the dryers is reduced to about 2 per cent. The dryers embody several novel features, providing for adjustment to suit both the class of coal and the moisture content, as also provision for controlling the temperature for drying and the cooling of the coal before its discharge.

The dryers are constructed in units, so that one or more units may be out of use as desired. Each unit comprises vertical sections, forming hollow walls for the passage of the coal to be dried, the sections being arranged in polygon form around a central flue. The coal is delivered from the washery by a conveyor to hoppers, which form the upper part of the dryers, and the hollow walls are thus filled by gravity. These are constructed slightly wider at the base than at the top to ensure free movement of the coal, and are also so constructed as to permit of the passage of the heating gases. Around each dryer unit is fixed an air trunk which is connected with a suction fan, whereby the hot gases are drawn up the central flue and through the walls of coal. The moisture is thus extracted with the moist gases or air.

The arrangement of these vertical walls of coal provides a large effective area for the passage of the drying gases, which are admitted near the base of the dryers and regulated by a valve. At the outer side of each wall valves are also provided to ensure even distribution of the gases. The walls are sub-divided horizontally so that the coal can be cooled in the lower section before discharge.

Discharge is effected and controlled at the base, where the coal falls from the walls on to a slowly revolving table, the speed of which may be varied as desired, thus providing for variation in the time of passage of coal through the dryer. The coal is finally delivered from the table by means of "ploughs" to an inclined belt conveyor for transference to an elevated bin, from which the dried coal is discharged as required to one or other of the main reception bins for the fuel-making process.

Not only does the drying equipment deal with coal from the washery, but other special "blend" coals, which, while not requiring washing, have too high a moisture content, can be delivered to the dryers.

Briquetting Process.—The main reception bins already referred to are provided at their outlets with revolving tables for automatically measuring the delivery and blending of the different classes of coal to be used in the manufacture of the fuel. These table measurers, which each have a capacity of up to 120 tons of coal per hour, are served by pans connected with the bins, each pan being fitted with two adjustable doors for regulating the delivery of coal to the table. Discharge from the table measurers is effected by means of "ploughs," and the respective coals then pass into a continuous worm conveyor, which serves to mix them together and with the binding materials, the binder being added to the coal in this mixing conveyor.

The pitch binder is first discharged from its reception bin into a crusher, from which it is raised by means of a bucket elevator to a smaller delivery bin. From this bin it passes to a specially designed rotary measuring apparatus, which may be adjusted while in motion to any required proportion. Before discharge into the continuous worm conveyor or mixing conveyor, already referred to, the pitch is granulated in a disintegrator. Other binding ingredient is also added to the correct proportions of coal and pitch, which have been delivered to the conveyor.

The worm conveyor, which provides for preliminary mixing, serves a large and totally enclosed bucket elevator, the function of which is to feed granulators of special construction, wherein the fuel mixture of coal and binding ingredients is reduced to granular form.

After granulation the fuel mixture passes by way of a screen and rotary feeder on to a short belt conveyor, which serves a large bucket elevator which delivers the granulated mixture into a main distribution bin provided with three outlets. From the centre outlet the mixture passes by means of a steel chute into a vertical pug mill heater. The other two outlets serve two distributing elevators, each of which feeds a subsidiary distributing bin, which also supply another two heater pug mills by means of steel chutes.

The fuel mixture having been thoroughly heated by means of highly superheated steam, and agglomerated in the pug mills to a proper consistency and temperature, is then delivered to the pans of the presses by means of conveyors of the paddle type. During its passage through the conveyors it is tempered or cooled to the correct degree for moulding into briquette form. The pans of the presses are provided with stirrer arms which serve to feed the finished fuel mixture to the mould tables of the presses, thus ensuring proper filling of the moulds.

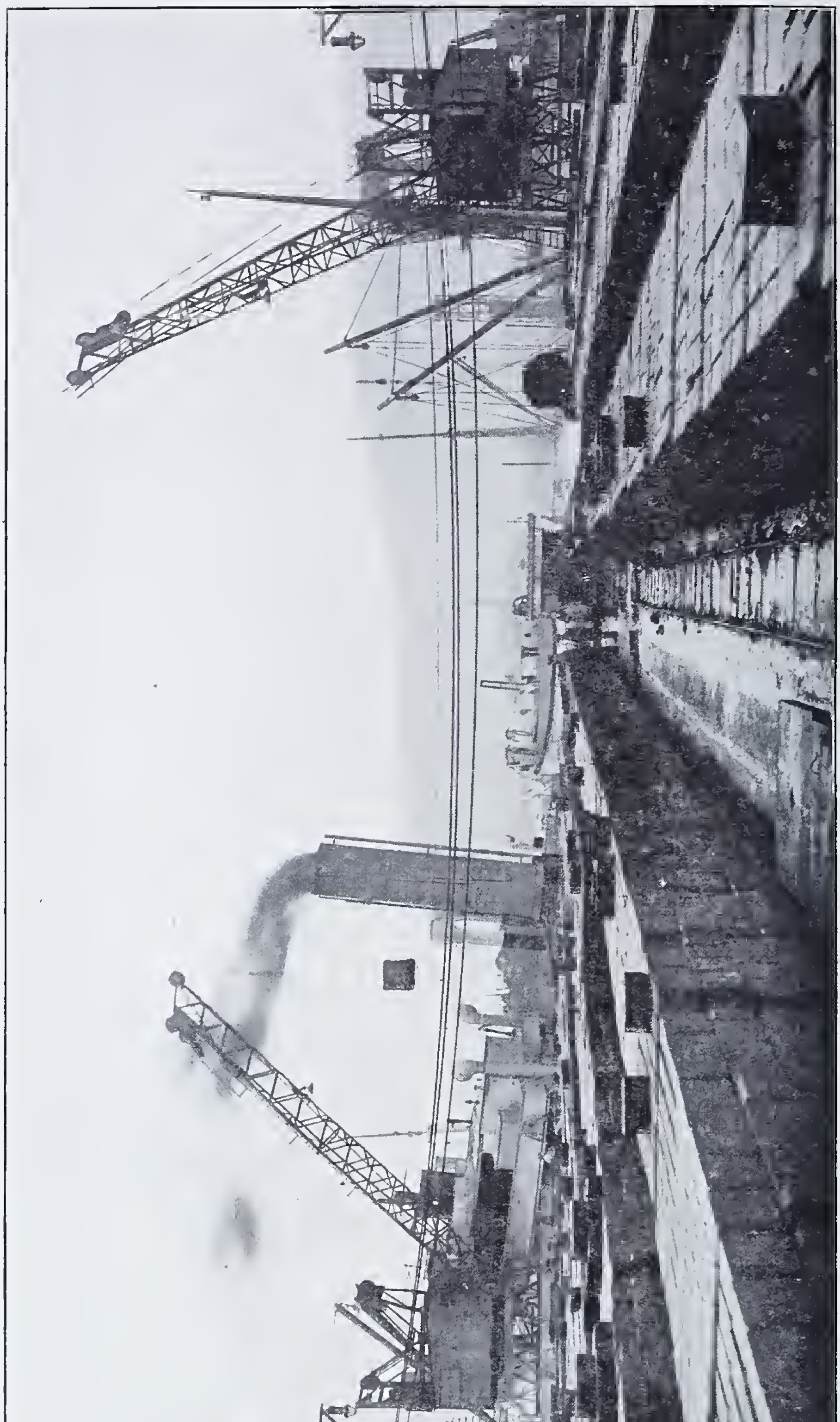


FIG. 55.—LOADING "ROSE" PATENT FUEL.

The presses are of improved design and construction. Each press has two tables, and each table is provided with eight moulds, the moulds having variable capacity and interchangeable liners of special metal. It is thus possible to produce sixteen briquettes of from 22 to 26 lbs. each (10 or 12 kgs.) weight, or alternatively thirty-two briquettes of about 11 lbs. (5 kgs.) each at every revolution of the tables. The normal capacity of a press is from about 29 tons to 35 tons of briquettes per hour.

Each press is fitted with a clutch, enabling either of the two tables to be started or stopped independently. The briquettes are automatically pushed off the tables of the presses on to roller conveyors, which are designed for automatic operation. The conveyors feed forked elevators which raise the briquettes to a loading stage above the press floor, where they are delivered to other roller conveyors and loaded on to platform trolleys of about 35 cwts. capacity. The briquettes are thus cooled and stored on an extensive stage ready for shipment.

Special attention is directed to the scientific selection of coals, which are purchased to meet definite and specified conditions. Chemical laboratories are provided completely equipped for analysis and testing of the coal, binding ingredients, fuel mixtures, and the finished briquettes, which are systematically analysed.

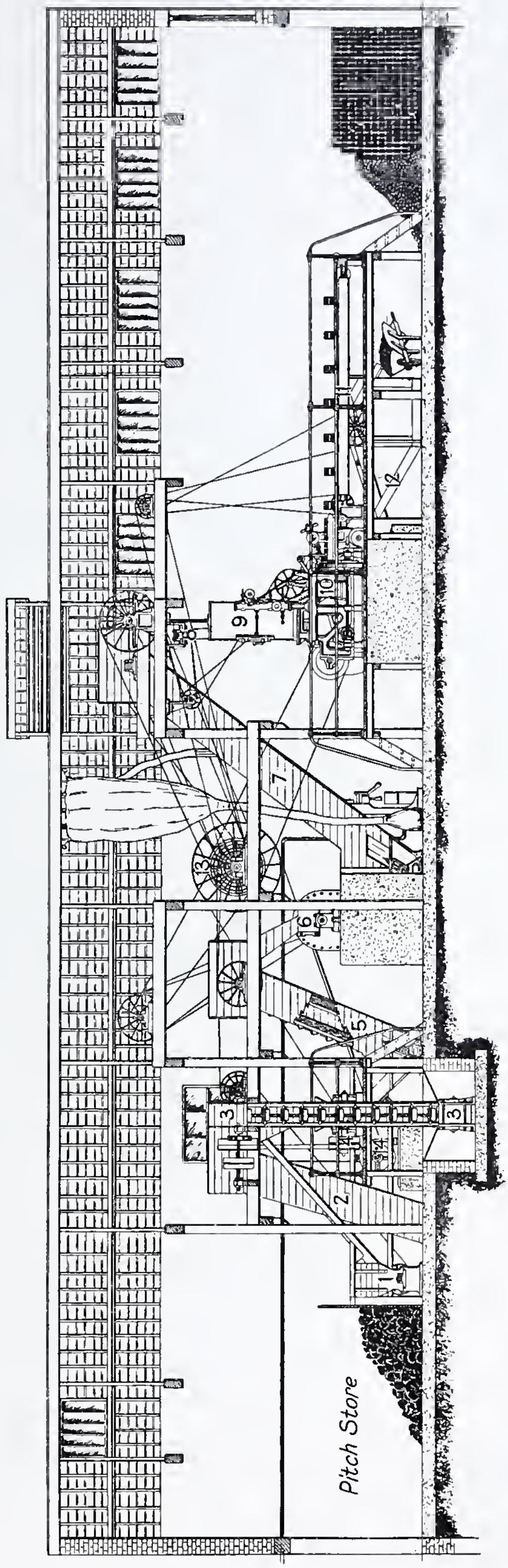


Fig. 56.—General Arrangement of Leeds Briquetting Works (Messrs Yeadon, Son & Co.).

1. Pitch cracker.
2. Pitch elevator.
3. Coal elevator.
4. Mixer or measurer.
5. Coal and pitch elevator.
6. Disintegrator.
7. Coal and pitch elevator to machine.
8. Worm conveyor.
9. Vertical heater.
10. Rectangular briquette machine.
11. Rectangular conveyor.
12. Ovoid conveyor.
13. Main shafting, 120 R.P.M.
14. Motor.

The power equipment comprises steam boilers with a triple expansion engine, electricity supply, both for power purposes and lighting, and also hydraulic power for certain special requirements.

The buildings, which are steel-framed structures, comprise three main sections—the press house, the power house, and the mixing and measuring section at a lower level. Adjoining this section are the main reception bins, which are also roofed in.

Immediately outside the building, and adjoining the press house, is the storage and shipping stage, an imposing structure of ferro concrete, which is the full width of the press house, and extends to the shipping wharf.

Extensive sidings are available for the storage of coal in wagons, and also large ground storage space. For the handling of the briquettes the arrangements are very complete, comprising a very comprehensive trolley stystem, with automatic weighing machines and electric cranes, the trolleys upon which the fuel is stacked when discharged from the press house being lifted by the electric cranes and lowered into ships' holds for unloading and stacking. Generally these works may be said to embody not only the latest improvements in manufacture, but also the most complete facilities for mechanical handling and labour saving.

The output of this works is mainly for export, the briquettes being largely used for locomotives. In Fig. 55 is shown a view of a steamer being loaded with Rose patent fuel.

The illustration, Fig. 56, shows the general arrangement of a briquetting plant at Leeds, manufactured and installed by Messrs Yeadon, Son & Co., the well-known briquette machinery makers, in order to demonstrate upon a practical and commercial scale the possibilities of briquetting various classes of fuel.

The main floor of the works is arranged at the railway level, so that coal and pitch as delivered can be discharged directly to the boot of the coal elevator and pitch cracker respectively, while the platform provides for loading the briquettes direct into railway wagons on the one side, or into vehicles for local delivery on the other side.

The pitch after passing through the cracker is elevated to the mixer, where it meets the coal raised by the coal elevator. The mixed material passes down a chute and over a magnetic separator into the disintegrator, from which it is raised by a bucket elevator and delivered into a screw conveyor placed between the two pre-heaters serving the Rectangular and Ovoid presses respectively. The conveyor is so arranged that the whole of the material may be delivered to either press or apportioned to both presses simultaneously. The crushing, mixing, and auxiliary plant generally is equal to the full capacity of both presses.

The presses which are shown in Fig. 57 are arranged side by side. The Ovoid press, which has a capacity of 4 tons per hour of 3 oz. Ovoids, delivering its product on to a short conveyor, upon leaving which the briquettes are sufficiently cool for loading. A certain proportion of the output is dispatched in railway wagons, but the bulk is bagged.

The Rectangular press has a capacity of 6 tons per hour, and produces four $2\frac{1}{2}$ lb. briquettes in one operation, the variation in weight not exceeding half an ounce.

This press is provided with a simple absolute locking motion, which eliminates the possibility of over-running. The machine discharges on to a short band conveyor, from which the briquettes are removed by hand for loading or stacking.

In Figs. 58 and 59 respectively are shown the latest types of Yeadon briquette presses, the former being a standard Ovoid press having a capacity of 10 tons per hour, while the latter is a standard Rectangular press having a capacity of 10 to

FIG. 57.—YEADON OVOID AND RECTANGULAR BRIQUETTING PRESSES AT LEEDS BRIQUETTING WORKS.

12 tons per hour. Fig. 60 illustrates the simultaneous discharge and loading of Rectangular and Ovoid briquettes at the Cramlington Colliery of the Cramlington Coal Co., Ltd., the former being taken from a conveyor and hand stacked, while the latter are being discharged from an overhead conveyor into a second line of wagons.

The illustration, Fig. 61, is a composite view showing on the floor 91 lbs. of small coal and 9 lbs. of pitch, and on the table twenty-five $2\frac{1}{2}$ lb. Rectangular briquettes and two piles of $2\frac{1}{2}$ oz. Ovoids, the product of the 100 lbs. mixture. For the use of this photograph the author is indebted to Messrs Yeadon, Son & Co., of Leeds.

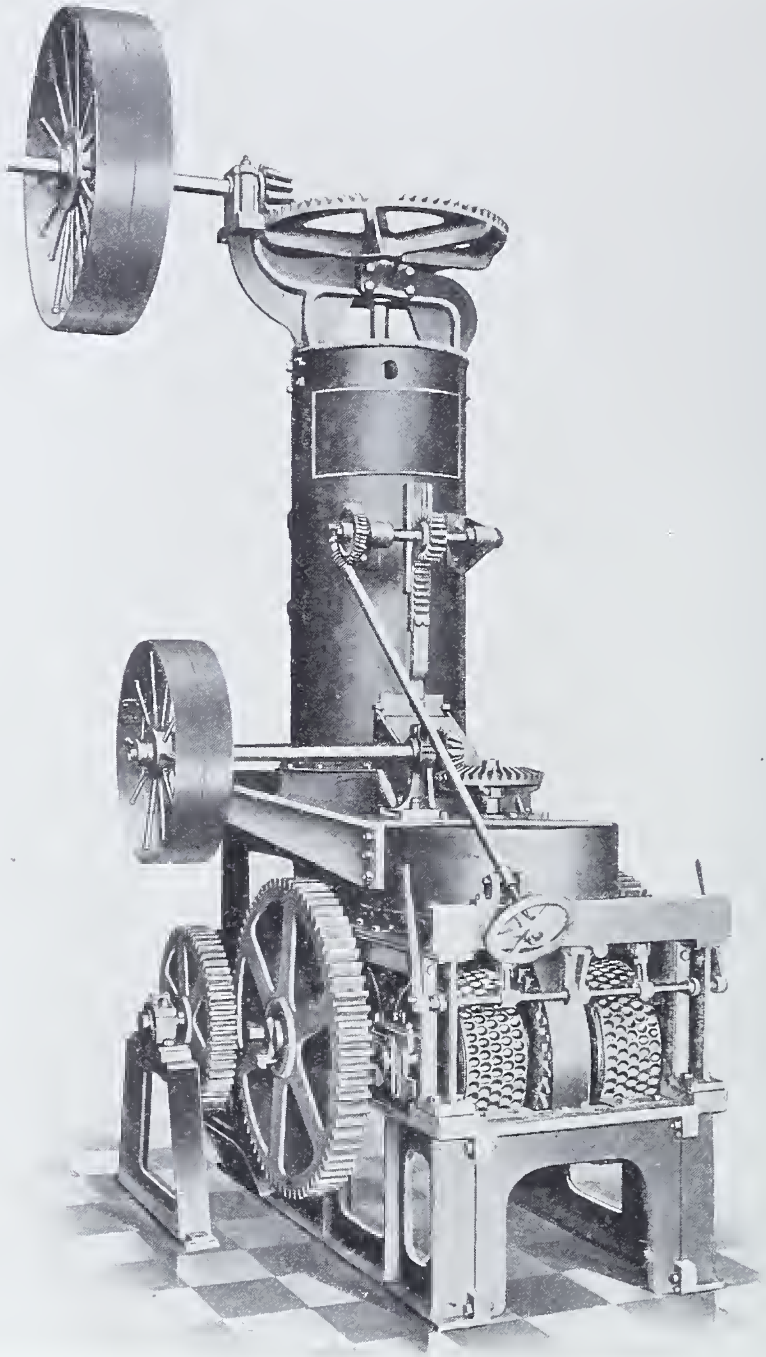


Fig. 58.—Yeadon's Standard Ovoid Briquetting Press.
Capacity, 10 Tons per Hour.

Two briquetting plants designed by Messrs W. Johnson & Sons, Ltd., of Leeds, are shown in Figs. 62 and 63 respectively, the former being a standard Ovoid plant,

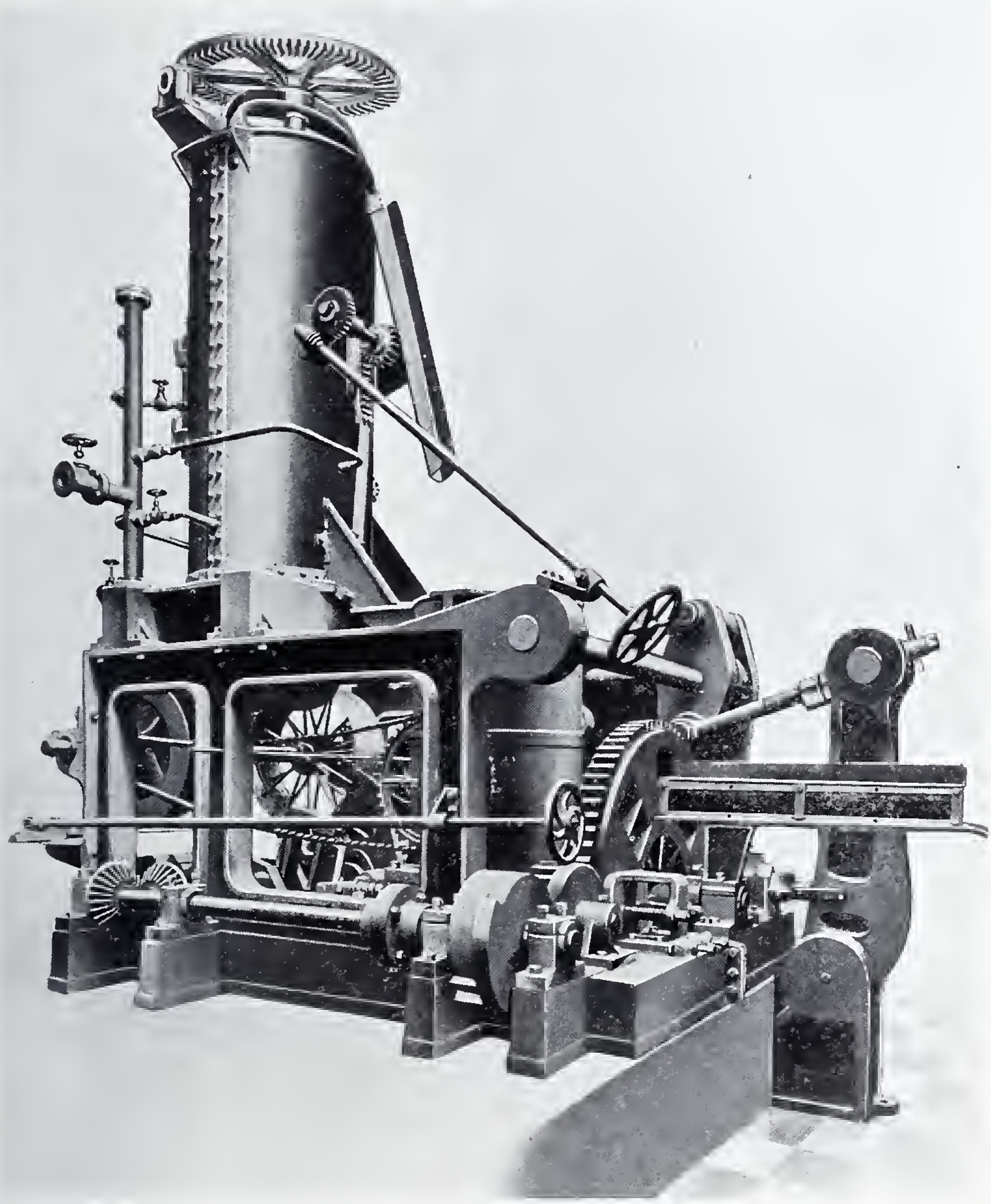


Fig. 59.—Yeadon's Standard Rectangular Briquetting Press. Capacity, 10 to 12 Tons per Hour.

having a capacity of 10 tons per hour, and the latter a plant capable of producing either 20 tons of Rectangular briquettes or alternatively 20 tons of Ovoids per hour.

Referring to Fig. 62 the coal may be discharged direct from railway wagons into the bunker A, from which it is lifted by the elevator B into the hopper C, which has a capacity sufficient to supply the plant for from two to three hours.

The pitch when delivered is stored in the basement D, where it is cracked to about 1-inch cube or less in the pitch cracker E, and raised by the elevator F into the pitch storage hopper G, the capacity of which is equivalent to that of the coal storage hopper C, already referred to.

Beneath the hoppers, C and G, automatic measuring apparatus is provided, arranged to measure and deliver both coal and pitch in the required proportions into the mixer H.

In the mixer the coal and pitch are intimately mixed, being then carried forward and delivered to the disintegrator J, where the mixture is reduced to a fine

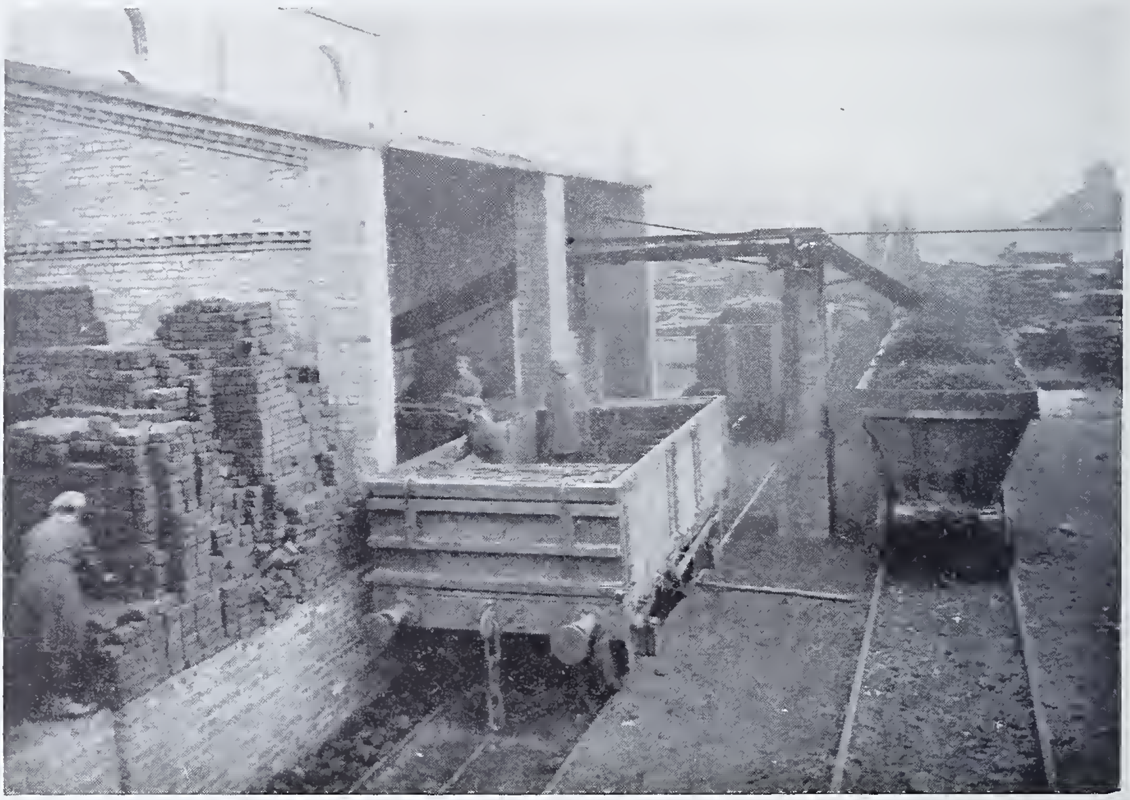


Fig. 60.—Loading Briquettes at Cramlington Colliery.
(Cramlington Coal Co., Ltd.)

powder and further incorporated, after which it is lifted by the elevator K and discharged in the service hopper L. This hopper has a capacity equal to supplying the plant for from one to two hours.

From the service hopper L the mixture is discharged by gravity to the vertical heater or fluxor M, where superheated steam up to a temperature of about 500° F. (depending upon the class of coal, pitch and moisture content) is injected into the mixture, which is kept in gentle motion by means of a stirring shaft. This combined action brings the mixture down to the required even consistency.

In this condition the mixture is too hot for use, and is therefore fed from the

heater into a cooling conveyor N, which delivers it to the press, at the same time by atmospheric exposure sufficiently reducing the temperature for briquetting.

From the cooling conveyor the mixture is delivered to the press O, in which the Ovoids are moulded and discharged on to a conveyor or other suitable receptacle.

From this point the method of handling adopted depends entirely upon particular or individual requirements. In the scheme shown in Fig. 62 the briquettes are discharged from the press on to a conveyor, which in turn discharges on to a distributing conveyor, which delivers the finished Ovoids into loading bunkers, which

FIG. 61.—COMPOSITE VIEW, SHOWING SMALL COAL, PITCH, AND BRIQUETTES.

may be arranged to discharge either into railway wagons or into a ship's hold. The distance between the loading bunkers and the press is arranged to provide for cooling in transit so that the briquettes in cooling form a hard skin.

The plant illustrated in Fig. 63 is operated in precisely the same manner as the plant already described, with the exception that the Ovoid section of the plant is served by means of a conveyor from the service hopper A.

In connection with the Rectangular briquette section of the plant, the process is identical up to the stage when the briquettes are discharged from the press. At this stage they are lifted on to flat bottom trucks which are run out to the storage space.

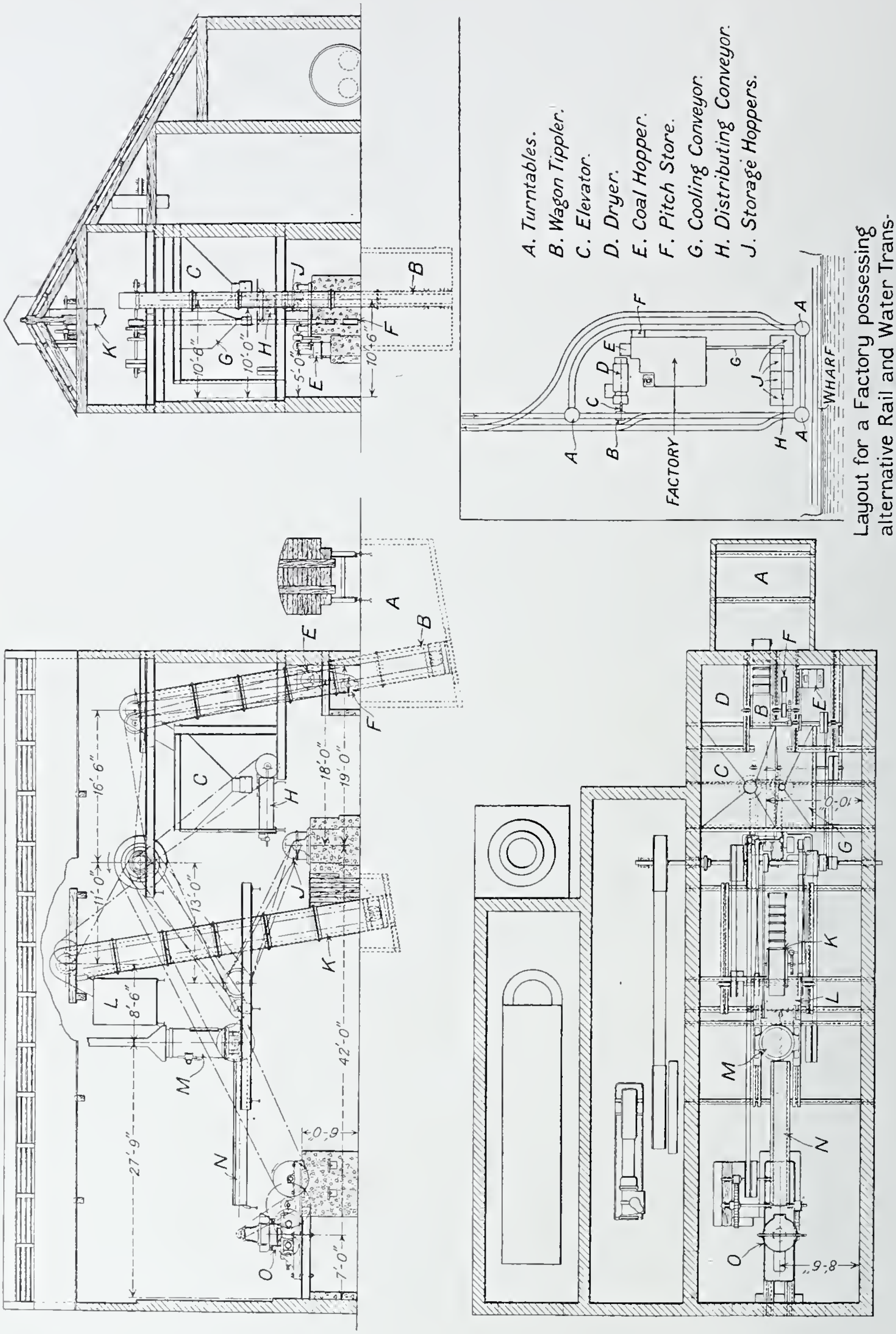


FIG. 62.—COMPLETE INSTALLATION FOR OVOID BRIQUETTES (STANDARD JOHNSON PLANT).

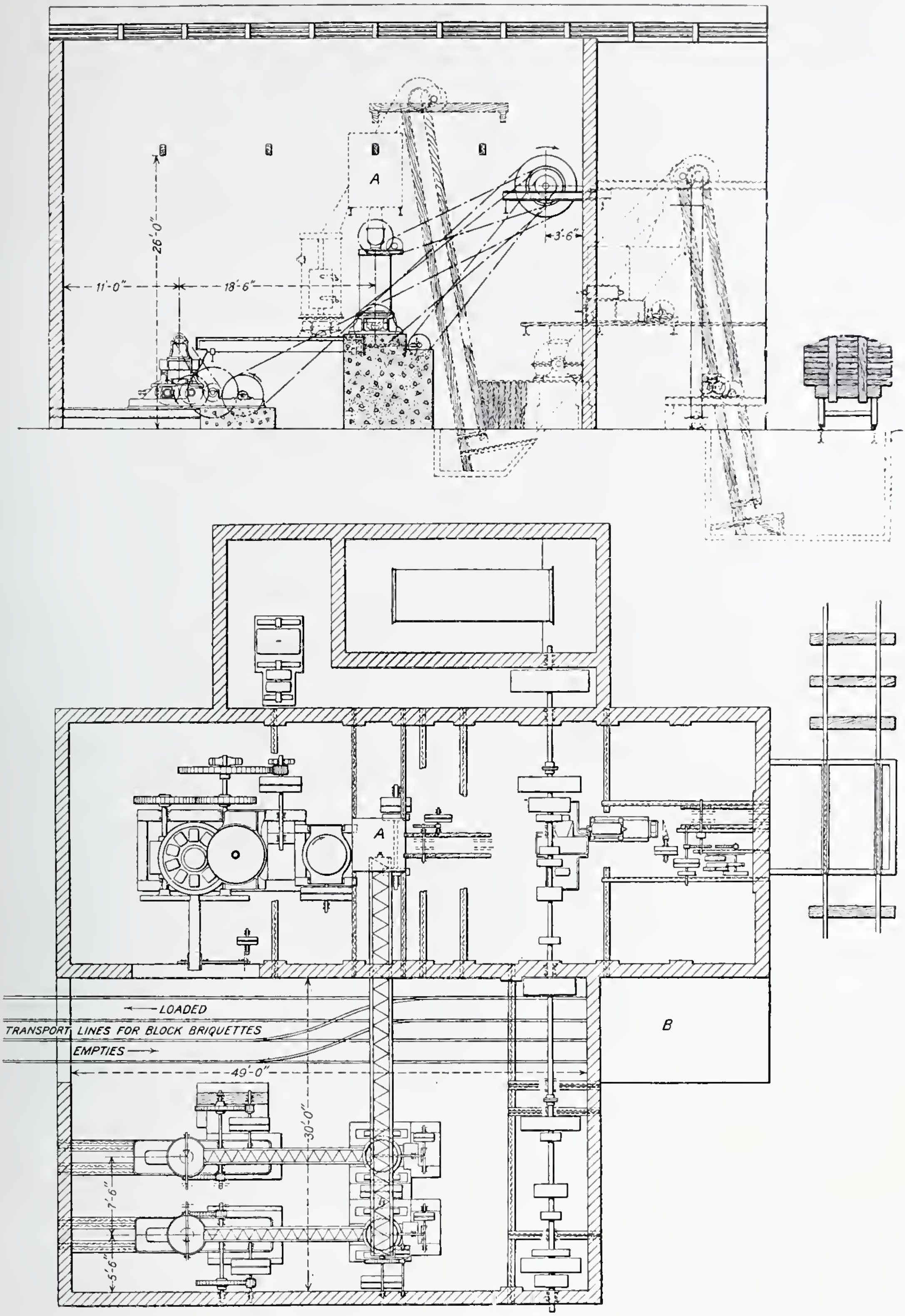


Fig. 63.—Complete Alternative Johnson Briquetting Plant, for Rectangular or Ovoid Briquettes.

Here it is desirable that the briquettes should be left for about forty-eight hours to cool and harden, after which, if required for sea transport, the loaded

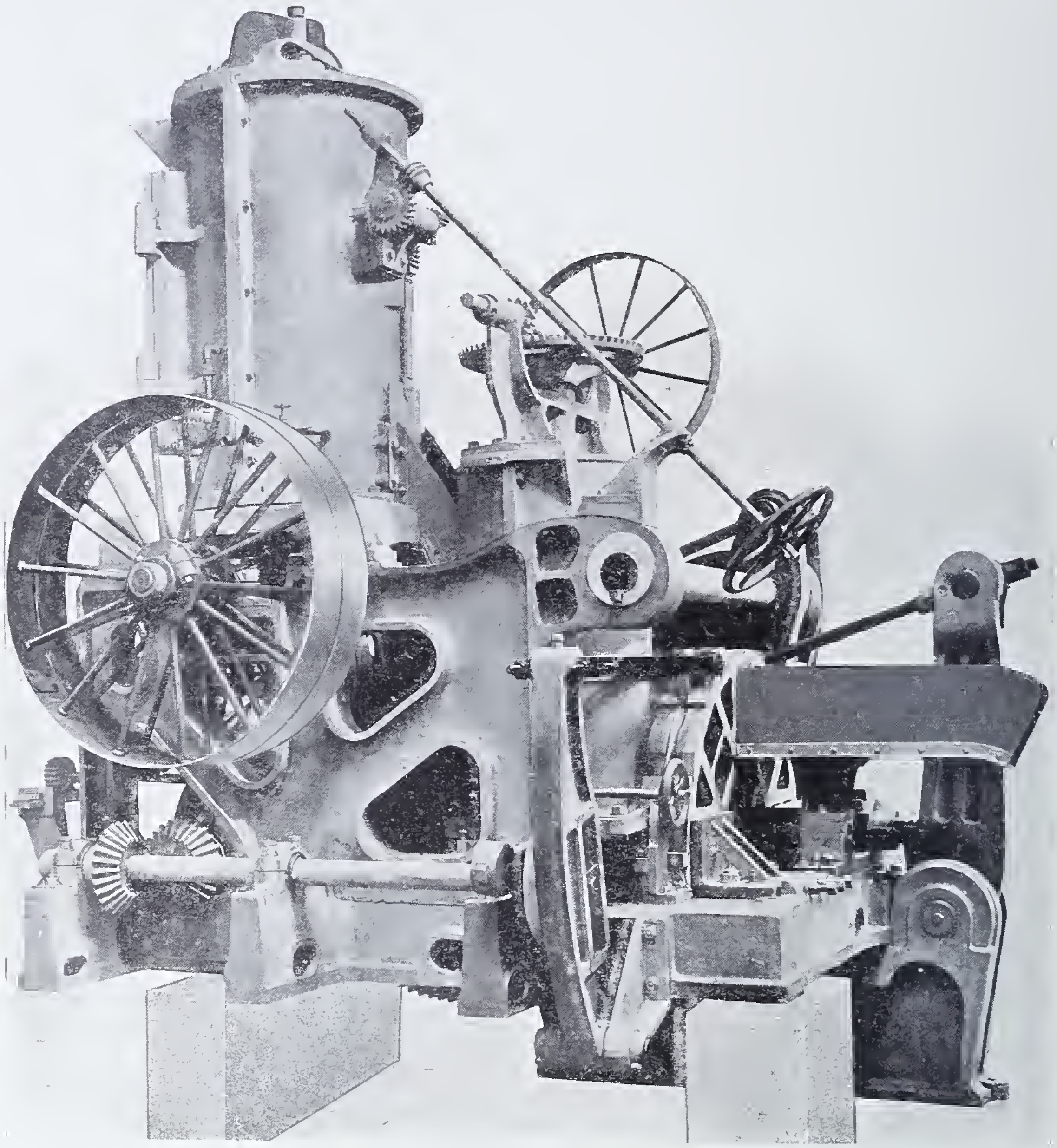


Fig. 64.—Johnson's Vertical Table Rectangular Briquetting Press.

truck may be lifted and lowered into the hold of the ship, the blocks then being removed and stacked.

In the case of rail transport the loaded trucks are run alongside the railway wagons, which are loaded by hand.

Fig. 64 shows Messrs Johnson's latest type vertical table rectangular briquette

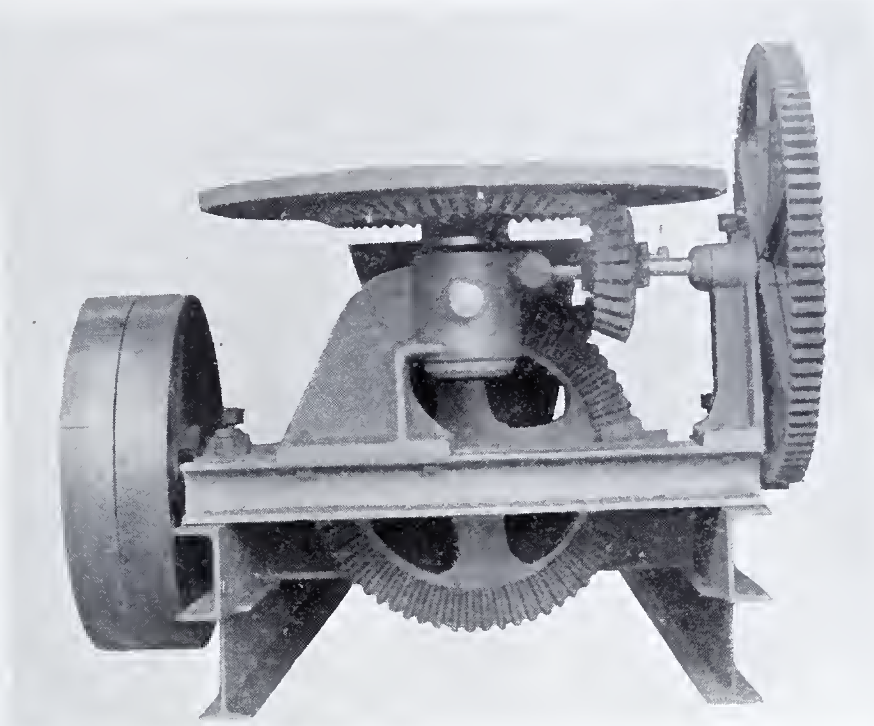


Fig. 65.—Johnson's Revolving Table Measurer.

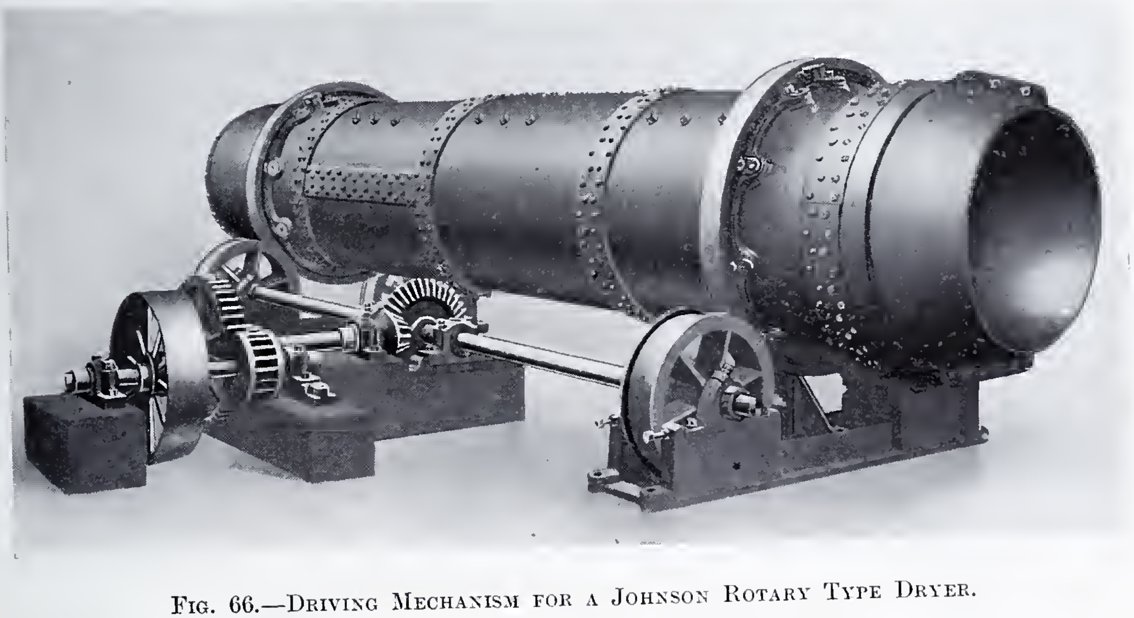


Fig. 66.—Driving Mechanism for a Johnson Rotary Type Dryer.

press, in Fig. 65 the revolving table type of measurer which is connected direct to the mixer is shown, and in Fig. 66 the driving mechanism for a rotary type dryer.

Briquetting without a Binder.—Hitherto the manufacture of briquettes without the use of a binding medium has been limited to the briquetting of brown coal in Germany, but, as the result of many years of experimental and research work, a company founded by the late Lord Rhondda—Pure Coal Briquettes, Ltd.—have perfected a process of briquetting without the use of a binder.

Briefly the process comprises initial grinding of the coal to a required condition of fineness, and then briquetting it under heavy pressure, in specially designed presses, either of the "Emperor" or Ovoid type. Ovoid briquettes may thus be made in any size required, and block briquettes up to 10 in. × 7 in. × 5 in. and weighing 15 lbs. each.

Alternatively if desired an "artificial coal" may be produced from fines in the form of irregularly shaped nodules, of a size suitable for industrial purposes. As no binding material is used, the analysis of the briquettes and the fuel from which they are made is identical. It has, however, been shown by comparative evaporative tests that the briquetted coal offers considerable advantages over the raw coal. These advantages may be briefly summarised as follows :—

(*a*) In most cases the briquettes are harder than lump coal, and will stand transport and handling better; this is particularly marked with soft coals.

(*b*) If made from house coal the briquettes burn admirably in a domestic grate, giving a fire which yields a more effective radiation than that from lump coal.

(*c*) For industrial use the briquettes are better than lump coal for the following reasons :—

(1) It is well known that the boiler efficiency obtained with briquettes is higher than that obtained with coal of equivalent calorific value.

(2) In a series of evaporative tests made at the South Wales School of Mines, comparative tests were made with a South Wales steam coal, pure coal briquettes, and patent fuel with a pitch binder, all from the same original coal, when it was shown that the pure coal briquettes were quite as smokeless as the original coal, that they gave a remarkably high value in heat transmission, that the rate of heat transmission was higher than from the original coal, that it was more advantageous in rapid steam generation, that a more even furnace temperature was maintained with a freedom from clinker adherence.

As the result of a test of 5 tons of pure coal briquettes carried out by officials of the French Admiralty, the opinion was expressed that the briquetted fuel was superior to South Wales steam coal.

It is claimed for these briquettes that they will comply with the specified requirements for manufactured fuel in stability, hardness, atmospheric exposure, and immersion in water. Further, that the smoke producing properties of pitch briquettes are not shown. With high volatile coal, it is possible to incorporate a

considerable proportion of coke breeze, but this fuel cannot be added unless the coal has a volatile content of from 25 to 35 per cent.

In a paper[1] read before the Society of Chemical Industry by E. R. Sutcliffe, Wh., Ex., A.M.I.M.E., and Edgar C. Evans, B.Sc., F.I.C., M.I.M.E., entitled "The Influence of Structure on the Combustibility and other Properties of Solid Fuels," the authors thus referred to briquetting and also the process of manufacture without the use of binding material.

(1) "Briquettes can be readily transported, handled, and stored for an indefinite period without deterioration. (2) Briquettes when burnt on locomotives under standard conditions show an increased boiler efficiency over coal of the same calorific value, amounting to 15 per cent. in favour of the briquettes. (3) It has been demonstrated that 25 per cent. more briquettes than coal can be burned per square foot of grate area per hour.

In other words, briquettes are more combustible than raw coal, a result entirely due to the difference in structure between briquettes and coal.

The principal advantages of briquettes can ultimately be attributed to their homogeneity both in respect to structure and to the size of the particles of which they are constituted.

Briquettes made with pitch in the usual way are not entirely homogeneous. The coarsely ground coal from which they are made is not uniform in size, and the pitch introduces a further complication.

A stage further in the direction of homogeneity can, however, be obtained by making briquettes without the addition of binding material, the briquettes thus consisting of uniformly sized particles of the raw coal itself, cemented together by the binding material in the coal substance. Briquettes of this type can be obtained by finely grinding the coal and subjecting it, under suitable conditions, to a pressure of about 10 tons per square inch. For all practical purposes briquettes of this type can be regarded as solidified coal dust, they are considerably more homogeneous in structure than any of the fuels yet dealt with, and a study of their properties serves to illustrate in many ways the effect of structure on the general properties of fuels.

Details of the comparative tests of raw coal, briquettes made with pitch, and pure coal briquettes, which have already been referred to, are given in the following table. These tests were made under uniform conditions, with a constant draught of 0·6 in. in each case. The briquettes made without a binder burned away so quickly that with the thin fires maintained it was found very difficult to keep the grate fully covered at the end of the charging period. The efficiency, therefore, was reduced, and a better result could have been obtained either by reducing the draught or working the boiler at a higher capacity.

[1] See Journal of the Society of Chemical Industry, June 30th, 1922, vol. xli., No. 12, pp. 196 T-208 T.

TABLE No. 34

Summary of Comparative Tests made at the South Wales School of Mines

Fuel.	Raw Coal.	Briquettes made with pitch.	Pure Coal Briquettes.
Ultimate Analysis—	Per cent.	Per cent.	Per cent.
Carbon	86·3	82·3	82·1
Hydrogen	4·3	4·0	4·1
Ash	4·2	8·30	7·71
Sulphur	0·95	0·98	1·15
Oxygen, Nitrogen	4·2	4·42	4·94
Moisture in coal	0·77	1·6	0·85
Analysis of Boiler Ash—			
Moisture	2·37	0·23	0·85
Ash	51·80	63·25	34·25
Carbonaceous matter	45·83	36·52	64·9
Flue Gas Analysis—			
Carbon dioxide	5·04	5·2	5·9
Carbon monoxide	nil	nil	nil
Oxygen	15·00	15·00	14·5
Nitrogen	79·96	79·80	79·6
Heat transferred to water per lb. of dried coal, B.T.U., lower value	7,246	6550·4	6,997
Calorific value of dried coal, B.T.U.	14,781	14,182	13,937
Heat transmitted per sq. ft. of heating surface per hour, B.T.U.	4,070	4,039	4,650
Weight of dried fuel fired per sq. ft. of grate area per hour, lbs.	13·78	15·05	16·3
Equivalent evaporation of water from and at 212° F. per lb. of dried fuel, lbs.	7·52	6·85	7·25
Weight of feed from and at 212° F. per sq. ft. of heating surface per hour, lbs.	4·225	4·225	4·81
Equivalent evaporation per lb. of carbon value of fuel, from and at 212° F., lbs.	7·31	7·31	7·55

These tests, while being admittedly imperfect in several respects, show that the combustibility of briquettes fuel increased with the degree of fineness of the coal, and with the homogeneity of the product.

As the result of research, it has been shown that pure coal briquettes offer great possibilities in carbonisation, both in the extraction of by-products and in the production of a smokeless fuel. By grinding the coal to a suitable size, approximately to pass through a 30-mesh sieve, with about 20 to 25 per cent. of previously carbonised coal, or coke breeze, and briquetting the mixture in an Ovoid press without a binder, a briquette is obtained which does not swell in the retort, but which will in fact pass through the retort without losing its shape, while the coke discharged will be either of the same size as the original briquette or a smaller size, depending upon the character of the coal used.

When the briquettes are to be carbonised it is not necessary to subject them to the heavy pressure required for the production of pure coal briquettes, it is only necessary to make the briquettes sufficiently coherent to stand up in the early stages of the carbonising process.

The washing of the coal in order to reduce the ash content to the minimum is desirable, as also drying.

Briquettes produced in the preliminary process can be carbonised in any gas retort or coke oven. The product obtained is a fuel eminently suitable for use in suction gas producers and for domestic purposes, either in open grates, or in anthracite stoves.

If carbonised in a coke oven it is claimed that the resulting product offers the following advantages over foundry coke :—

(1) It has properties very similar to charcoal in combustion. It is well known that charcoal furnaces have a carbon consumption frequently 30 per cent. lower than coke fired furnaces, and it is hoped that if this fuel be used on a large scale for blast furnace practice, that a saving of 2 to 3 cwts. per ton of pig-iron will be effected.

(2) The density of the coke is considerably greater than that of furnace coke, and owing to the greater space available for ore and flux, the capacity of the furnace will be increased by 15 per cent.

(3) The coke will retain its shape practically down to the oxidising zone of the bottom of the furnace. There owing to its active nature it will be consumed at a rate considerably greater than in the case of furnace coke, resulting in an intense concentration of heat at the point most required.

The manufacture of briquettes without the use of a binder, as also the carbonisation of such briquettes, and the production of a smokeless fuel, has great possibilities, and future development will be watched with much interest.

CHAPTER VIII

FUEL RECOVERY

THE recovery of saleable fuel by separation from waste fuel, ash, and clinker, is not an innovation. For many years past in the larger gas-works in this and other countries washing plant has been successfully used for the recovery of coke and coke breeze from pan ash from retort settings, and the percentage of graded fuel recovered has undoubtedly justified the installation of expensive plant.

Until within the past three years no plant of this kind has been available for the smaller gas-works, as also for the economical treatment of waste from steam boiler and other furnaces. While there has been a general desire upon the part of gas engineers to recover saleable fuel from waste, the capital cost of suitable plant has been much too high, and the cost of hand screening and picking has been prohibitive in many cases owing to the cost of labour. With the increased cost of coal, and accordingly the enhanced value of coke and breeze, the recovery of the maximum proportion of saleable fuel has become imperative. The recent development of simple and expensive plant for the separation and recovery of fuel from incombustible waste has led to its rapid adoption not only in Great Britain, but in other countries.

As will be shown, fuel recovery is no longer confined to gas-works. On the Continent such plant is now extensively used by railways, electric power stations, and industrial works.

The German railways, for instance, were formerly only able to utilise from 55 to 77 per cent. of the combustible in the coal, the balance—clinker, cinder, and ash—having been regarded as valueless, although it has since been shown to contain 50 per cent. or more of combustible material.

It was reported by the United States Consul at Frankfort-on-Main, that thirteen large recovery works, having a total handling capacity of 420,000 tons of ash and cinder per annum, are now either in operation or under construction. The quantity of coke obtained is estimated at 164,000 tons, with an average calorific value of 5500 B.T.U.'s per lb., compared with 7000 B.T.U.'s per lb. for hard coal. The fine coke, with the addition of fine coal, and hard pitch is used in the manufacture of briquettes ; about 74,000 tons of briquettes being thus obtained, having a calorific value of 6500 B.T.U.'s per lb.

The proportion of unburned and partially burned fuel which is lost in the removal of clinker and ash both from hand and machine fired furnaces, and not only in connection with steam boilers, is well known to be serious. This loss, which varies considerably, is due to a number of factors ; it may be as low as 10 per cent.

or even less, but in a very large number of works it is not less than from 20 per cent. to 30 per cent. So heavy is the loss of combustible through riddling, unsatisfactory combustion, and—in the case of hand fired furnaces—carelessness in the cleaning of fires, that this source of loss can no longer be disregarded.

Apart from the actual waste and loss of fuel, the cost of haulage and disposal of ash and clinker is a serious item in the cost of steam generation. Fuel recovery, therefore, is well worth serious consideration, not only because of the proportion and value of the fuel recovered, but also because it correspondingly reduces the cost of disposal.

Most of the systems of fuel recovery in use employ water, some of these processes will be described and illustrated as also a recently introduced German process of magnetic separation.

The Columbus Coke Separator

The Columbus coke separator, which is illustrated in Figs. 67 and 68, is now in use in a number of gas-works for the recovery of coke from the ashes from

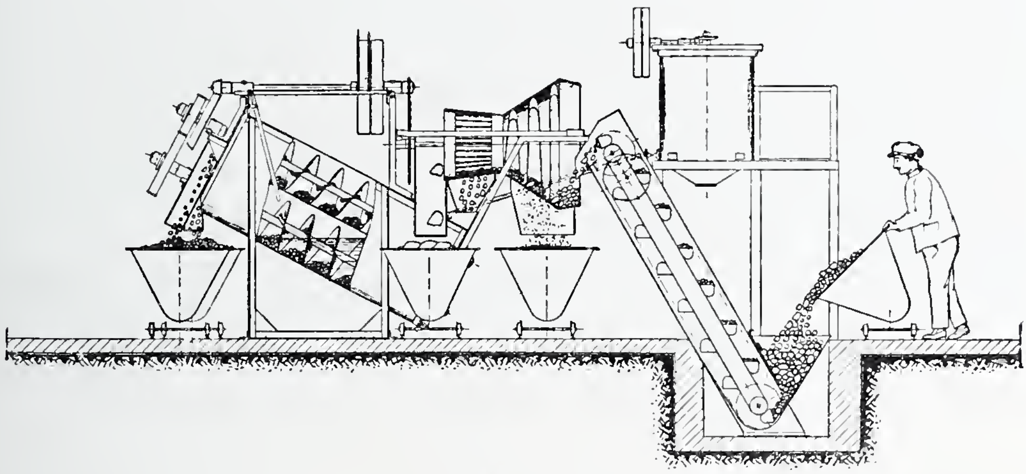


Fig. 67.—The Columbus Coke Separator.

regenerative retort settings. This simple type of separator, which is made in three sizes—viz., 2, 4, and 9 to 13 cubic yards capacity per hour—may be briefly described as follows :—

The apparatus comprises two main parts : a rotary screen into which the material is fed, and the separator proper. The material first passes a fine mesh rotary screen which rejects the fine dust, thence through a second rotary screen having a $3\frac{1}{4}$-in. mesh, which ejects the larger pieces of clinker. From this screen the material is delivered into the separator chamber, which consists of a sheet-iron container, within which revolve in separate compartments two super-imposed worm conveyors. The container is kept half filled with water, the specific gravity of which is increased by the admixture of clay, loam, or any similar suitable material.

Upon falling into this liquid the heavy clinker and incombustible sinks, while the lighter coke floats on the surface. The upper worm conveyor, which is so set

as to travel well below the working level of the liquid, conveys the combustible to a discharging shoot. The lower worm conveyor, which is set at the bottom of the tank, removes the incombustible, passing the same to a separate discharge shoot.

The smallest size of plant is arranged for feeding by hand, the larger sizes are automatically fed by means of an elevator conveyor. If desired in connection with the larger plants, additional screens may be provided to grade the recovered fuel in sizes down to $\frac{1}{4}$ in.

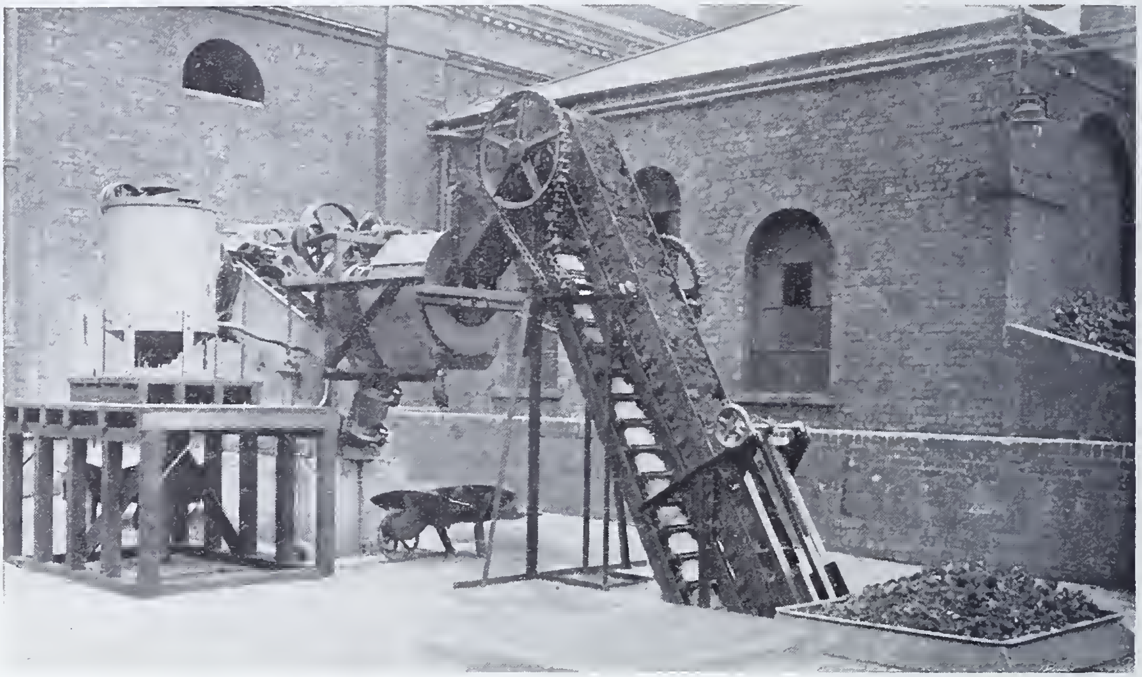


Fig. 68.—The Columbus Coke Separator at Richmond (Surrey) Gas Works.

The power required for operation varies from $1\frac{1}{2}$ H.P. to 4 H.P., according to the capacity of the plant, which requires but the minimum of unskilled labour.

A test of a Columbus separator of the smallest size at the works of the Richmond Gas Company, Richmond, Surrey, in November 1922, with wet pan ash breeze gave the following results :—

	Tons.	Cwts.	Qrs.	Cubic yards.	Per cent.
Weight of pan ash breeze treated	6	9	2	= 10	..
Weight of coke recovered .	2	12	0	= 4·5	=40·3 per cent.
Weight of fine dust and breeze recovered . . .	1	15	0	= 2·75	=27·1 ,,
Weight of clinker . .	2	2	0	= 2·75	=32·6 ,,

The time occupied in treating 10 cubic yards of ash as above was 3 hours 50 minutes.

The following tabulated data showing the percentages of coke recovered with Columbus separators at a number of gas-works, not only show a remarkable uniformity, but also serve to demonstrate that the percentage recovery is such as to more than justify the provision of recovery plant.

	Coke. Per cent.	Clinker. Per cent.	Fine Ash. Per cent.	
Blackburn .	44	23	33	
Brighton . .	43	32	25	
Hampton Wick	54·1	16·7	29·2	
Lea Bridge .	41·6	21·5	36·9	
Nelson . .	42·15	26·44	31·41	
Oxford . .	43·1	25·0	31·9	
Richmond .	40·3	32·6	27·1	
Southampton .	53·12	22·39	24·47	Coal gas plant
,, .	41·66	31·94	26·38	Carburetted water gas plant

Croydon Gas Company

Type of separator.	Motor power.	Date.[1]	Weight of pan breeze treated.			Weight of coke recovered.			Weight of fine ash recovered.			Weight of clinker recovered.			Difference in weight in and out of machine =water and clay.		
			T.	C.	Qrs.	T.	C.	Qrs.	T.	C.	Qrs.	T.	C.	Qrs.	T.	C.	Qrs.
C	6 H.P.	April 24	21	8	1	11	18	1	8	8	1	5	14	1	1	12	2
						=45·68%			=32·24%			=21·87%			=6·14%		
C	6 H.P.	April 26	17	11	1	7	14	0	6	5	0	4	10	1		18	0
						=41·72%			=33·87%			=24·25%			=4·87%		

The Coulson Pan Breeze Washer

The Coulson pan breeze washer, which combines a rotary washer with a screen for grading, is perhaps one of the best-known types in use in the larger gas-works both in London and in the provinces for the recovery of coke and coke breeze from what is generally known as pan breeze.

Although the arrangement of the plant may be varied to some extent to meet particular requirements, in its standard form it comprises a rotary screen in combination with a rotary washer barrel or drum ; the screen is used for the separation or grading of the material into various sizes, and the washer to separate the clinker from the coke. The water used may be returned through the cycle repeatedly, the whole plant being driven by means of a gas engine or any other source of power preferred as may be most convenient.

A typical Coulson plant at the Nine Elms Gas-Works of The Gas Light and Coke Company which is driven by a 40 H.P. gas engine may be thus briefly described :—

The pan breeze brought from the several retort houses is fed into the boot of a

[1] Pan breeze from coal gas plant.

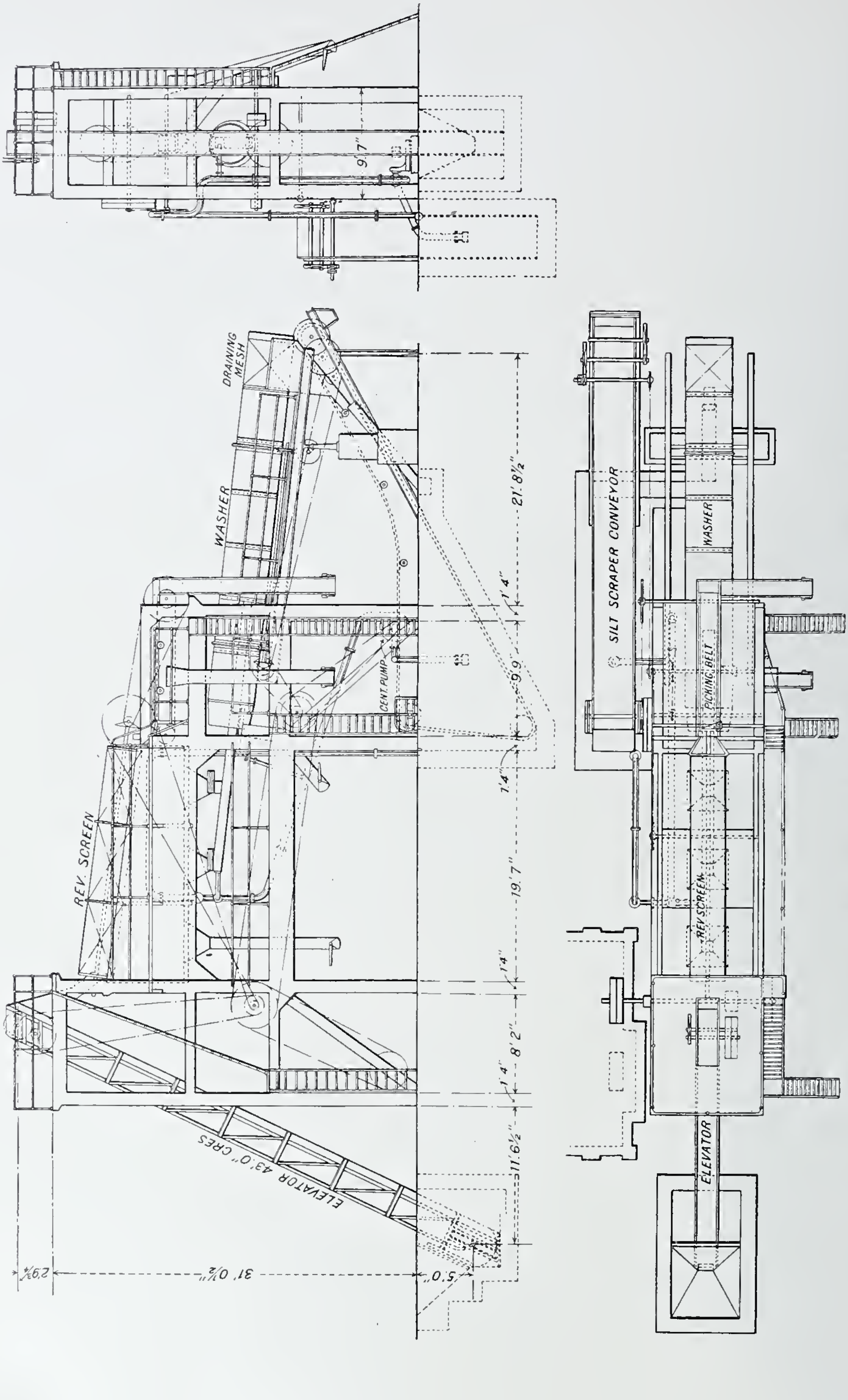


Fig. 69.—The Coulson Pan Ash Washing Plant.

bucket elevator through a grating at floor level, the larger lumps being broken by hand. The elevator delivers the material to an inclined rotary screen, in three sections: dust, fine, and large. The dust is delivered into a shoot from which vehicles may be loaded, the fine and the large material pass to their respective steel plate bunkers. The large material which does not pass through the screen falls from the end of it on to a picking band, from which the large pieces of clinker are removed by hand, while the large coke drops from the return end of the belt into a loading spout.

With two sizes of material available in their respective bunkers—*i.e.* fine, and large—these are now ready for separate treatment in the rotary washer, with which the bunkers communicate by means of a slightly inclined spout, into which the

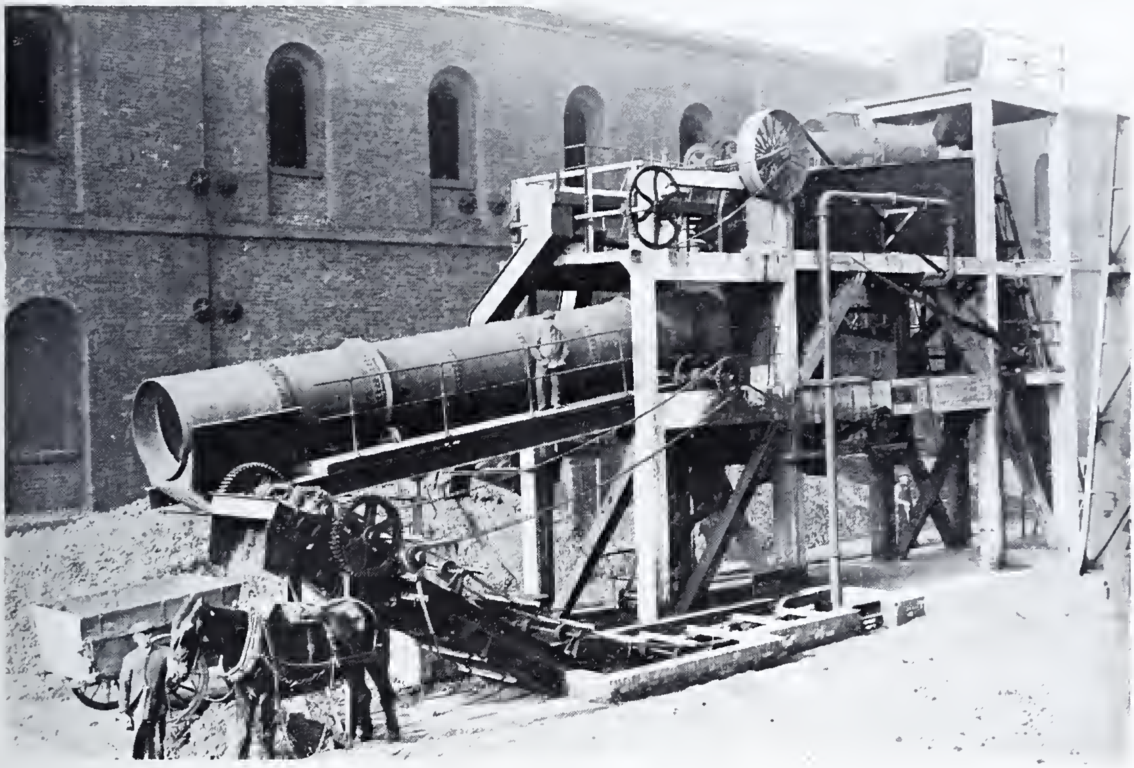


Fig. 70.—The Coulson Pan Ash Washer.

water for washing is delivered by a centrifugal pump. The pan breeze is thus flooded down into the washer barrel. This barrel is set at a slight inclination, and for the greater part of its length is made of solid plate, only a few feet at the lower end being finely perforated to allow the water to drain off from the coke, the water returning to a settling tank below the structure, whence it is drawn back again by the centrifugal pump. A dredging elevator is provided for periodical removal of the silt, provision also being made for preventing the choking of the pump suction. Clean coke is discharged at the lower end of the washer barrel, which internally has two helixes; the one in the upper or solid portion of the washer is

so arranged as to discharge all clinker at this point, while the lower helix in the perforated end of the washer discharges the clean drained coke or breeze as the case may be.

The Coulson washer is illustrated in Figs. 69 and 70.

The Méguin Ash Washer

The Méguin ash washer, made by Méguin Actien Gesellschaft of Butzbach, Hessen, Germany, is illustrated in Fig. 71, the method of operation being as follows :—

The ashes are tipped on to a grid covering the pit (*a*), the grid comprising bars

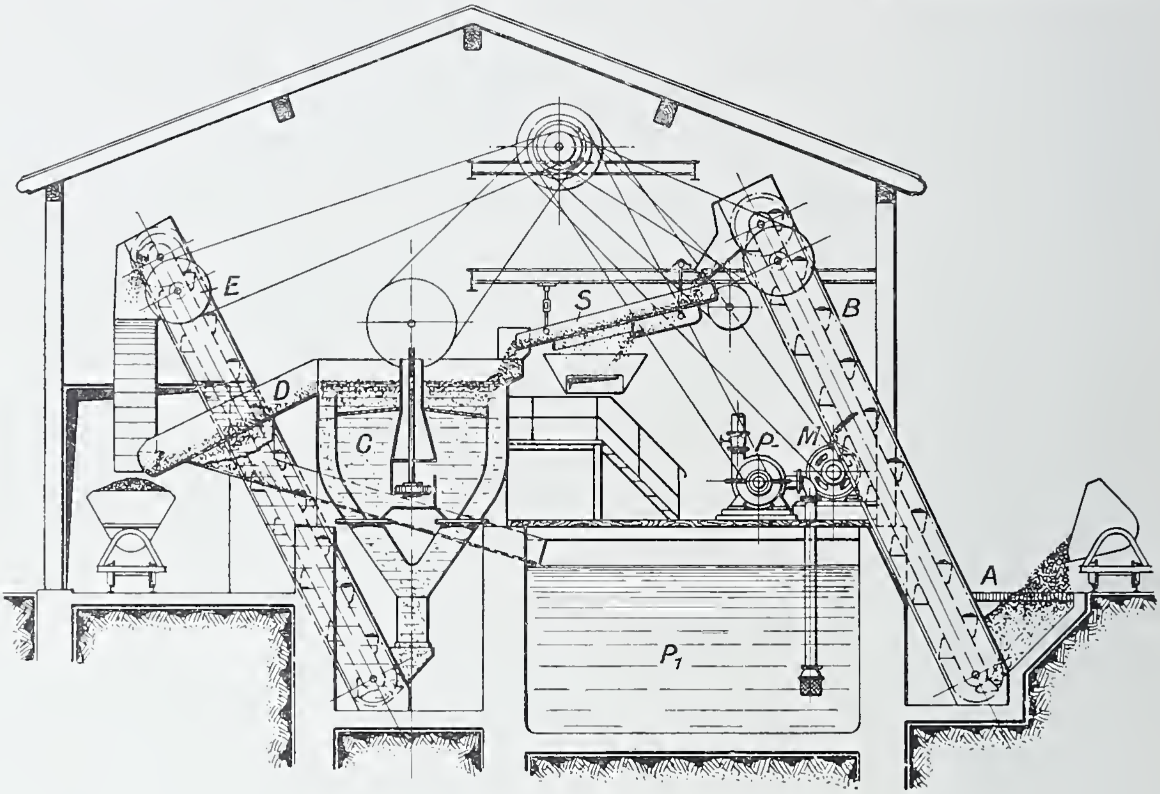


Fig. 71.—The Méguin Ash Washer.

spaced about 70 mm. apart; lumps over 70 mm. in size are retained on the grid, and if composed of combustible entirely, or in combination with clinker, may be broken or picked out by hand. The material then drops into the hopper of the elevator (*b*), by which it is delivered on to the classifying screen (*s*), where it is separated into two sizes, viz., from 0–8 mm., which material is usually rejected, and 8–70 mm., which passes into the washer (*c*), where the combustible is separated from the incombustible. The former, being lighter, passes over the washer, while the heavier and incombustible material passes through the washer box, leaving at the base, and passing into the dirt elevator (E).

The recovered coke passes from the washer on to the rigid screen (*d*), where it is

drained, and is then finally delivered into waggons. The incombustible residue is lifted by the elevator and discharged into trucks or waggons for removal.

The water used in the washing process is drained into the settling tank P 1 and conveyed to the washer for further use. The plant may be driven from an existing shaft or by means of a motor and intermediate shafting. In Fig. 72 is illustrated a Méguin ash washer at Wandsbeck Gas-Works, near Hamburg, where it is claimed that the percentage recovery is from 50 to 60 per cent.

The type of Méguin combined ash washing and briquetting plant as used for

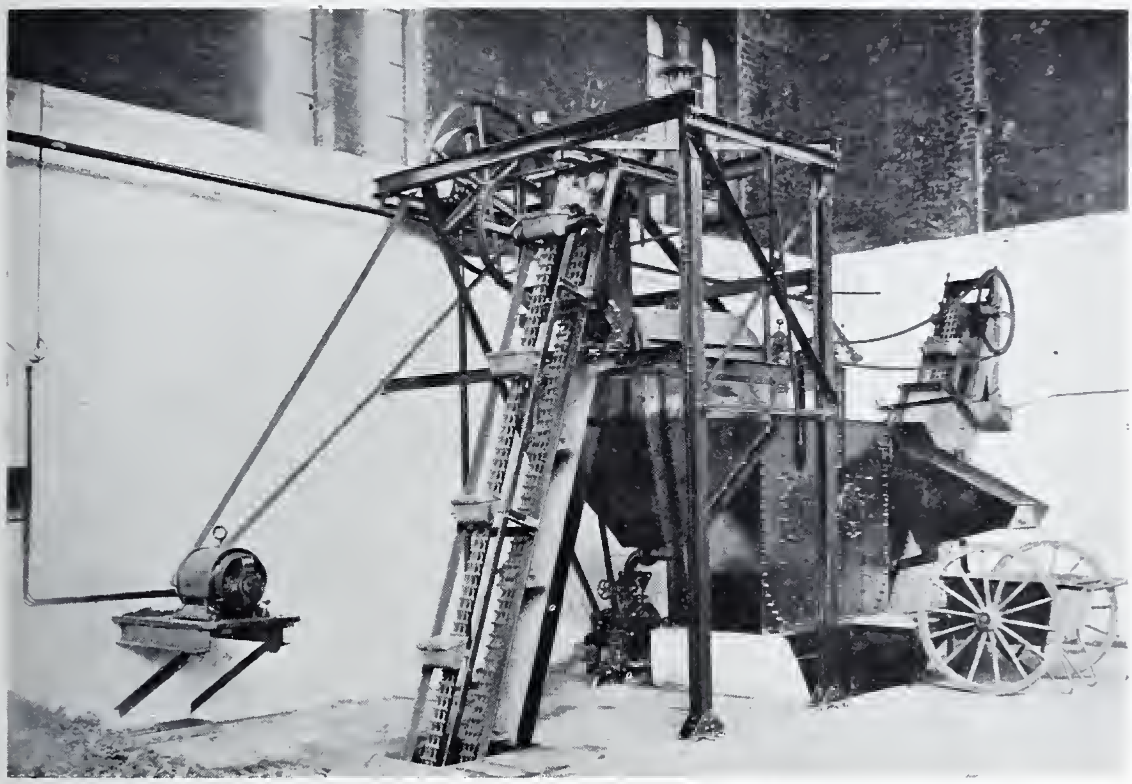


Fig. 72.—The Méguin Ash Washer at Wandsbeck Gas Works, near Hamburg.

the treatment of locomotive ash, in Germany, which has already been referred to, is illustrated in Fig. 73. The method of operation is as follows :—

The material to be treated is discharged into the supply pit by means of a waggon tippler. A charging cylinder which is capable of slide adjustment conveys the material to the pit of the charging bucket elevator, whence it is delivered to a large classifying drum.

In this drum the material is graded from 0 to 8 mm. and 8 to 20 mm., and is thence delivered to two special bunkers fitted with a regulating device, from which it is discharged on to two quadruple field magnetic separators.

These two separators extract the combustible from the incombustible, delivering the latter into a bunker for removal, and the former into a storage hopper for further treatment. Both are so stored as to permit of removal direct from the bunkers into tip or railway wagons.

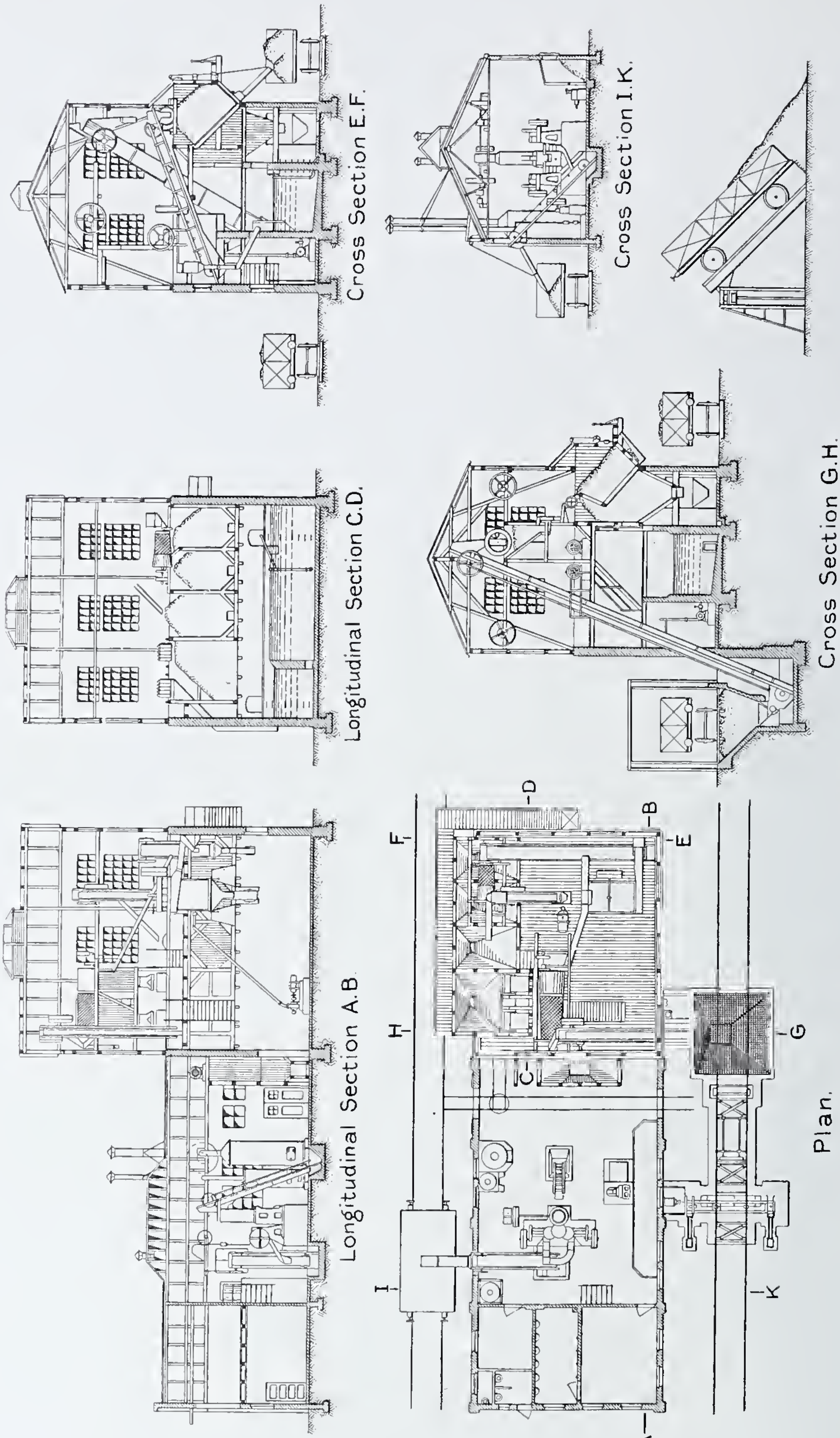


Fig. 73.—The Méguin Combined Ash Washing and Briquetting Plant.

From the fuel storage hopper the smallest fuel, 0 to 8 mm., is conveyed to the briquetting plant, and the larger fuel, 20 to 80 mm., is conveyed by means of a chute from the screening drum to the washer, or, if desired, to the picking belt.

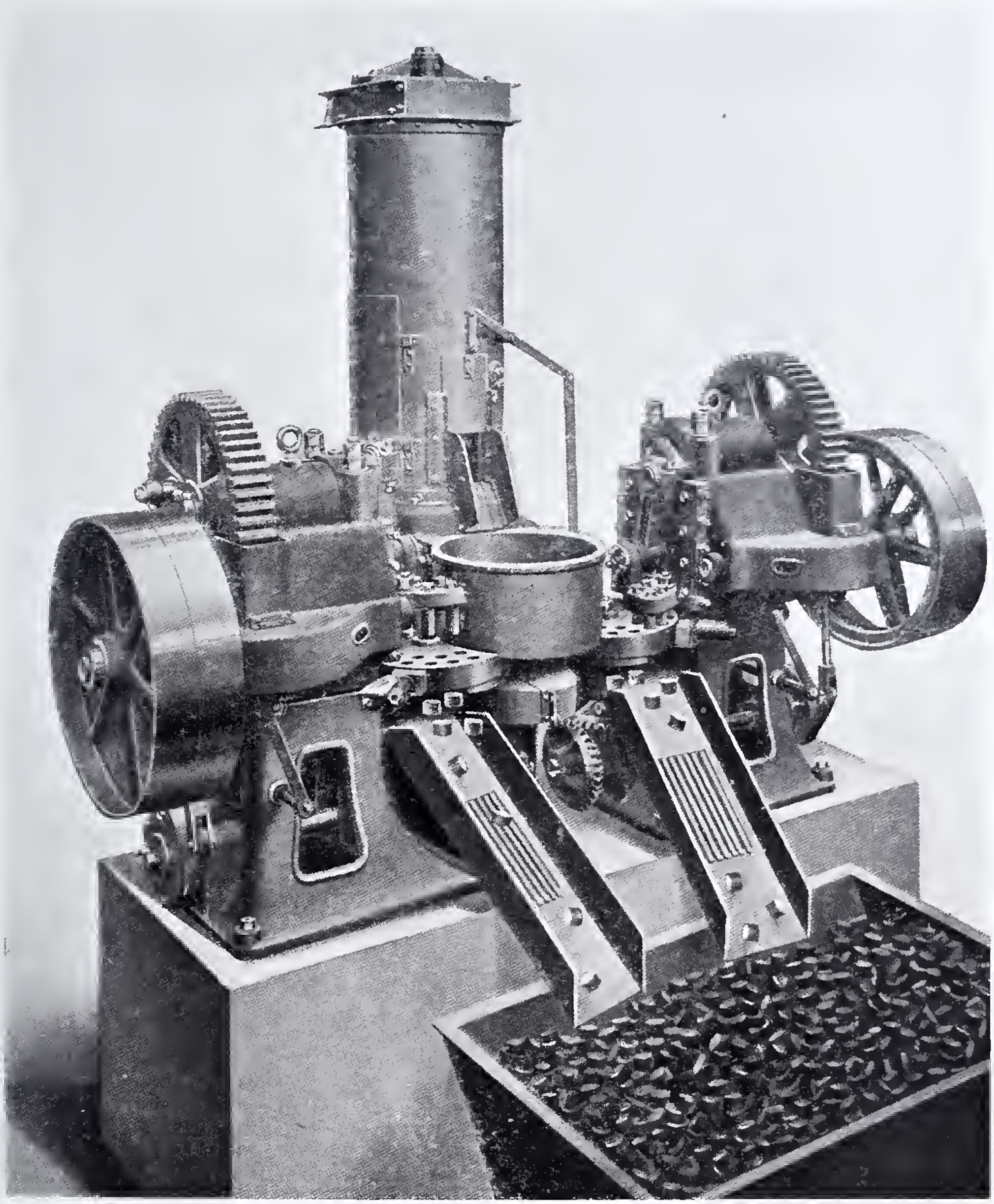


Fig. 74.—The Méguin Waste Fuel Briquetting Press.

The washer, which is a special patented feature of this process, is of the piston type, with which it is claimed a complete separation of the ash from fuel is effected. The recovered combustible is delivered on to a screen for drainage.

From this screen the fuel is conveyed to a picking belt, where any porous clinker or incombustible not previously separated is removed before the fuel is delivered

to a secondary screening drum arranged above the bunkers. In this drum the fuel is finally graded from 21 to 35 mm. and 36 to 80 mm.

The water used in the washer is run off into a precipitation or silt tank, and thence passes into a storage tank for future use, being lifted from this tank to the washer as required by means of a centrifugal pump.

The incombustible ash discharged from the washer is removed by means of

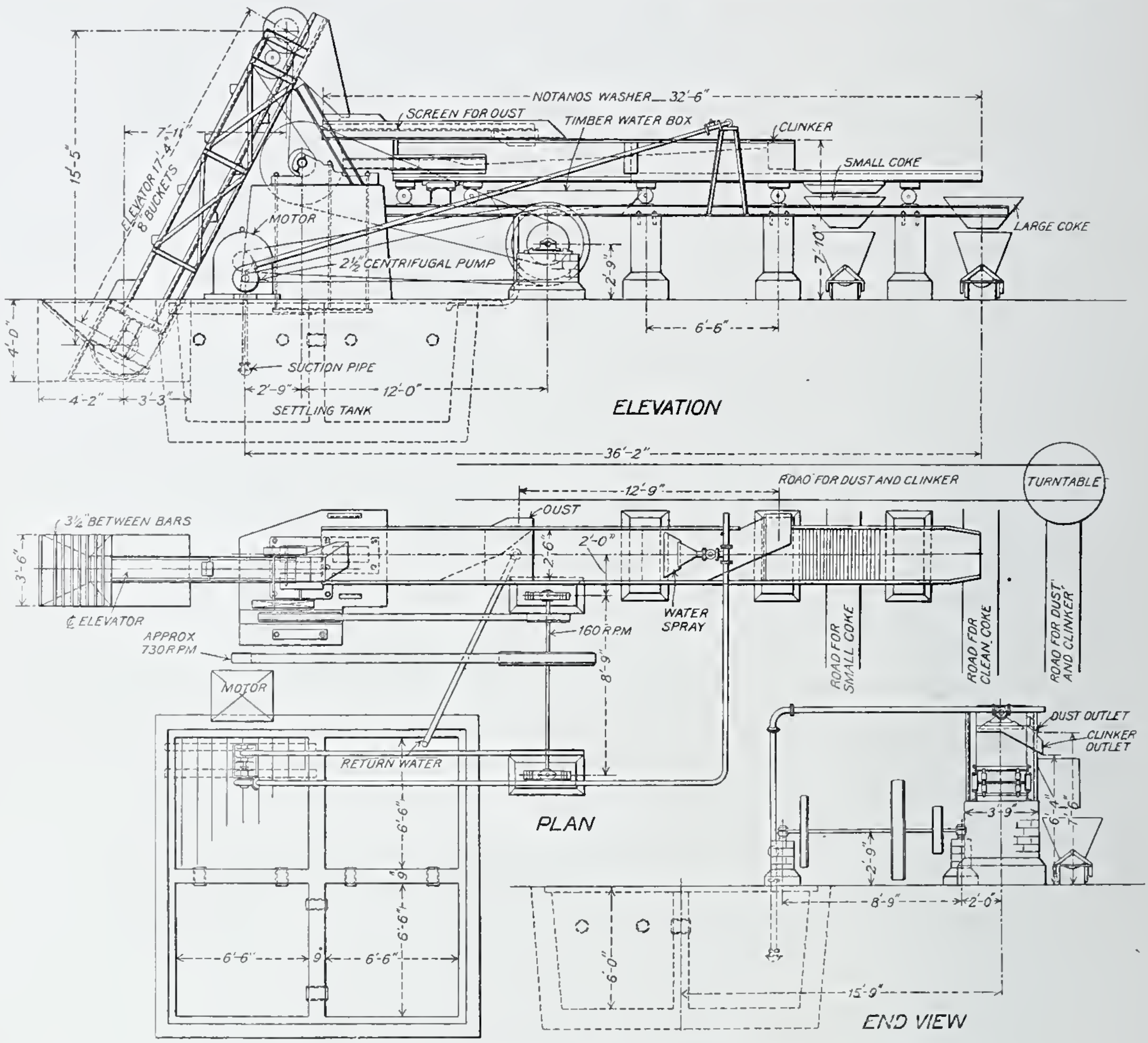


Fig. 75.—The Notanos Pan Ash Washer.

a bucket elevator into the ash bunker, from which it may be delivered direct to railway wagons.

The recovered fuel used for briquetting is mixed by hand with about 8 per cent. of pulverised hard pitch, which is ground in a pitch mill arranged at the floor level and adjoining the fuel hopper.

The mixture of fuel and pulverised pitch being delivered into the pit of a bucket elevator is lifted to the mixer, where it is very thoroughly mixed, superheated steam at a temperature of from about 270° to 350° C. being supplied to the mixer.

At the lower end of the mixing chamber a distributing device forces the mass into the moulds of the former plate. The briquetting press is provided with three pressing and three expelling dies. A typical Méguin briquetting press is illustrated in Fig. 74.

The briquettes, which are usually about 50 mm. long and 60 mm. in diameter, are discharged from the press over a screening chute on to a belt conveyor, which in turn discharges through an adjustable loading chute into railway wagons.

The "Notanos" Pan Ash or Coke Washer

The Notanos pan ash washer, which is illustrated in Figs. 75 and 76, has been extensively used for some years past in many of the principal gas-works in Great

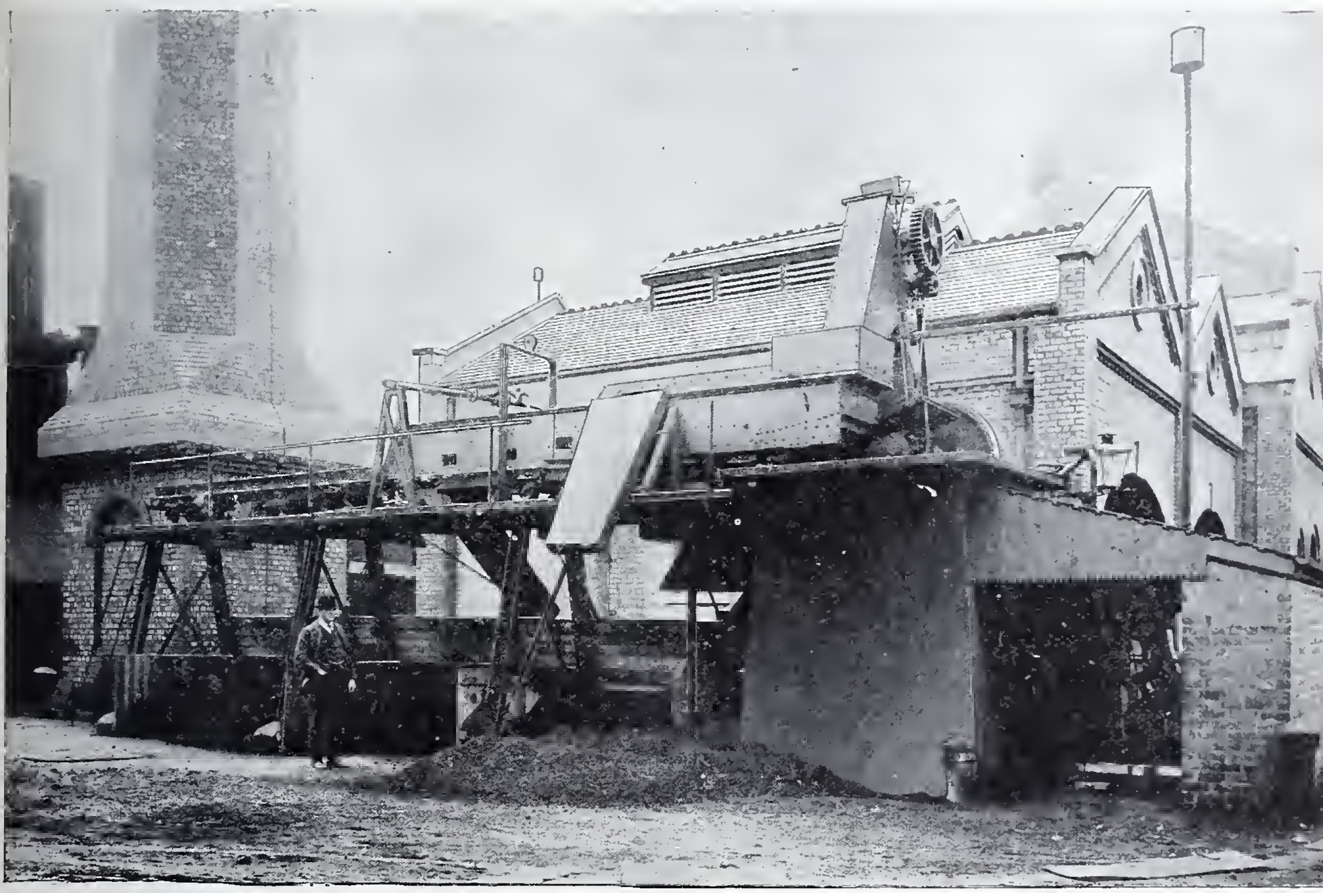


Fig. 76.—The Notanos Pan Ash Washer.

Britain, and also in Continental countries, for the recovery of coke and coke breeze from pan ash.

The washer is built up of mild steel plates, angles, etc., securely riveted together to make a box section trough, approximately 2 ft. 6 ins. wide by 32 ft. long. The trough is fitted with a screening deck, washing deck (set at an inclination), and draining deck carried on cast-iron rollers, having chilled treads supported on stools

of channel iron section. The paths of the rollers are fitted with renewable wearing flats, the rollers being held in position with steel spindles, coupled together with steel springs.

The driving gear mechanism is connected to the trough by means of a universal joint, which allows for any slight irregularities in the foundations due to settlement.

The driving gear comprises driving and propulsion shafts carried in substantial bearings lined with gun-metal steps, the bearings being securely bolted to a bed frame built up of rolled steel sections and plates. The propulsion shaft is fitted with an eccentric connecting rod, and the driving shaft is fitted with a heavy fly-wheel driving pulley. The power from the fly wheel is transmitted through the driving shaft to the propulsion shaft by means of a coupling or drag link. This driving mechanism imparts to the washer trough a practically uniform accelerated forward motion, giving a pulsating action to the recovered fuel when passing over the adjustable weir on to the draining deck, and a conveying action to the clinker, etc., sufficient to overcome the flow of water, and at the same time liberate any coke likely to be carried away with the clinker.

The method of feeding the washer is as follows :—The pan ash before being fed on to the washer screen is tipped on a grid having bars spaced from $2\frac{3}{4}$ in. to 3 in., in order to prevent the larger pieces of coke and clinker from being fed into the washer. The material which passes through the grid is fed on to the screening deck of the washer by means of an elevator or other suitable provision, and traverses the length of the screen, where material up to $\frac{3}{8}$ in. and under is taken out and is not washed.

Material exceeding $\frac{3}{8}$ in. in size falls over the end of the screening deck into the washer, where it meets a flow of water ; the water, combined with the action of the machine, separates the coke from the clinker or other material having a similar specific gravity.

The separated or recovered coke is carried down the trough with the flow of water and floats over an adjustable weir on to a draining deck beneath, where the conveying action of the machine carries the coke over the draining plate to a suitable point for discharge, either into a hopper or wagons as may be desired. If it is required to grade the coke, by extending the draining deck within certain limits and providing sizing grids, this may be done.

The water which flows over the weir with the coke passes through the draining plate, is collected, and flows to the tank for precipitation. This water is in constant circulation and use.

The clinker or waste of similar specific gravity, being heavier than the coke, falls to the bottom of the washing deck, and coming under the conveying action of the machine is carried up the washing deck against the reverse flow of water, and in the opposite direction to that taken by the water and coke, to be discharged from the trough at the high end of the machine.

The Notanos washer is very simple in operation ; it is open to inspection, easily adjusted, and, when once set to deal with one class or grade of material, does not require further attention.

The volume of wash water required in circulation is 120 gallons per minute, with sufficient make-up water to allow for waste, due to absorption by the treated material.

The capacity of the washer varies from 3 to 5 tons per hour and the power required for driving is 6 H.P. A modified form of this washer is used for coal washing.

Dry Recovery by Magnetic Separation

In a new fuel recovery process introduced by Fried Krupp A. G. Grusonwerk of Madgeburg, Germany, electro-magnetic separation is successfully employed.

This process is based upon the fact that practically all coals contain iron in the form of pyrites, having no magnetic properties, which as the result of burning is converted into oxides, which are susceptible of magnetic attraction. It has been shown that the whole of the iron found in the residual clinker and ash is in a very much more concentrated form than in the raw coal as fired, and these facts are taken advantage of in order to effect the separation.

As the result of exhaustive experiments, it has been shown that the ash from coal of every kind, even including lignite, may be successfully treated by magnetic separation and that on an average the percentage recovery of coal and coke exceeds 30 per cent. of the weight of the material treated, while in some cases it has reached 50 per cent. and even higher.

For capacities ranging from 5 cwts. up to 2 tons of ash per hour, a plant having one magnet drum is sufficient, the drum being provided with from one to four magnetic fields. The drum rotates slowly about an horizontal axis, similarly to the drum or pulley type of magnetic separator such as is used for the extraction of metal from coal in connection with pulverised fuel plant.

The material to be separated is fed on to the drum through a vibrating screen, which in the case of the larger plants may be fed by means of a bucket elevator. On the screen the material is graded into various sizes, each size passing separately to the drum.

The incombustible containing iron is held magnetically to the surface of the drum for half a revolution, and as the exciting current is broken, drops off the drum into tip trucks, wagons, or other receptacles as may be provided. The recovered coal and coke do not adhere to the drum but leave its surface directly after contact, and are automatically delivered into their own receptacles.

One very important advantage of this process of separation and recovery, as compared with other systems using water, is the fact that the process is *dry*. For this reason light, small, and porous incombustible does not adhere to the coke, thus the fuel recovered is clean, and not having been in contact with water there is no added moisture to evaporate.

It is claimed that the percentage of fuel recovery is higher than with any system using water, inasmuch as it is impossible with the latter system to avoid the loss of fine combustible.

The operation cost of magnetic separation plant is low, the electric energy

required for the magnet being from 0·8 to 1 k.w. per ton of ash and clinker treated, while the power required for driving the separator, including also the vibrating tray or screen, varies from $\frac{1}{4}$ to $\frac{3}{4}$ H.P.

If desired the magnetic separator may be combined with more than one screen, as also a picking belt and a bucket elevator. The plant is made of either the fixed or portable type, the latter being arranged on a wheel base.

A complete plant having a capacity of 3 tons per hour is illustrated in Fig. 77, the operation of which may be briefly described as follows :—

The ash is discharged from tip wagons on to a "grizzly," or grid, (1), which has a spacing of 75 mm. (3 in. square). From the larger pieces remaining on the

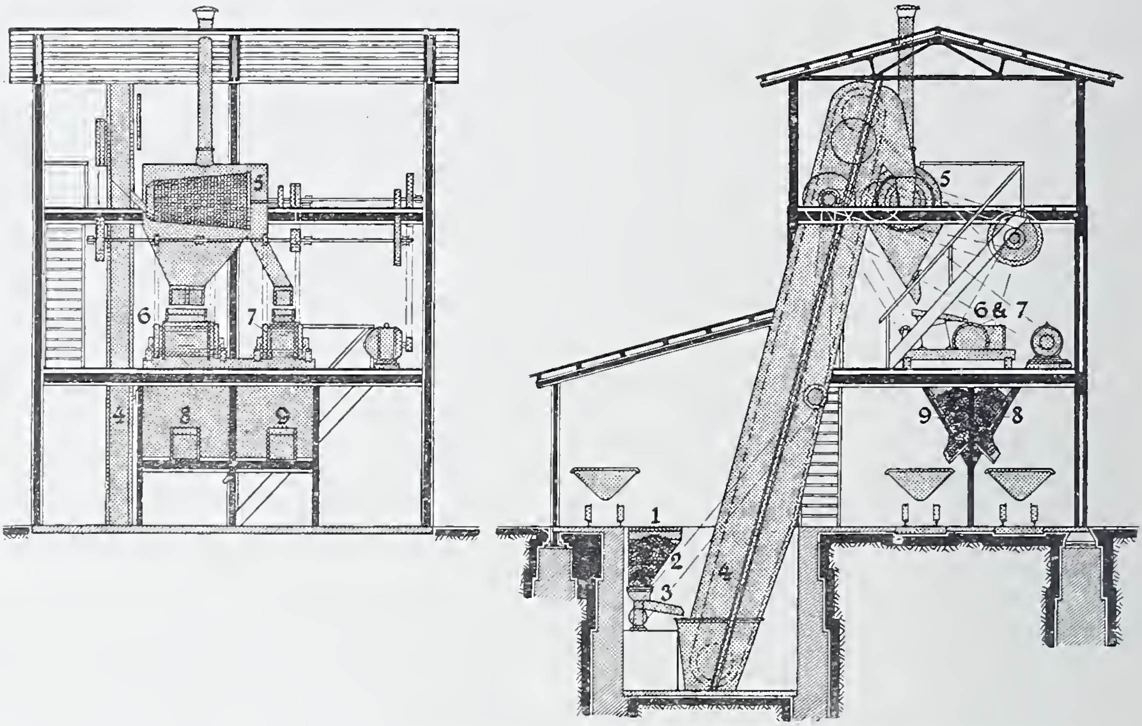


Fig. 77.—The Krupp Magnetic Separator. Capacity, 3 tons of Ash per Hour.

grid the incombustible and coke are picked out and removed, while the pieces comprising incombustible and coke in combination are broken up either by hand or in a stone crusher. All the material passing through the grid falls into the hopper (2) immediately beneath, from which it is conveyed by means of the vibrating chute (3) into the bucket elevator (4). The bucket elevator, which if desired may be replaced by a grab, conveys the material to the cone classifier (5), in which it is graded to various sizes, for instance 0 to 15 mm. (0 to $\frac{5}{8}$ in.), 15 to 35 mm. ($\frac{5}{8}$ in. to $1\frac{3}{8}$ in.) and 35 to 75 mm. ($1\frac{3}{8}$ in. to 3 in.). The fines from 0 to $\frac{5}{8}$ in. pass on to the magnetic separator (6) and the material from $\frac{5}{8}$ in. to $1\frac{3}{8}$ in. to the magnetic separator (7), while the coarser pieces from $1\frac{3}{8}$ in. to 3 in. pass on to a picking belt. The recovered coke and coal are delivered into the bin (8), while the incombustible is delivered into bin (9), from which the material may be separately discharged into vehicles as desired.

In Fig. 78 is shown a portable or travelling magnetic ash separator having a capacity of 2 tons per hour treating locomotive ash for the Hungarian State railways.

Fuel Recovery from Town's Refuse

The recovery of fuel from town's refuse in the form of cinders and small rejected coal was advocated during the war by the National Salvage Council as a feature of some importance in the salvage and utilisation of waste.

Under the conditions which then obtained the primary object in the screening and sorting of refuse was the recovery and utilisation of various classes of waste

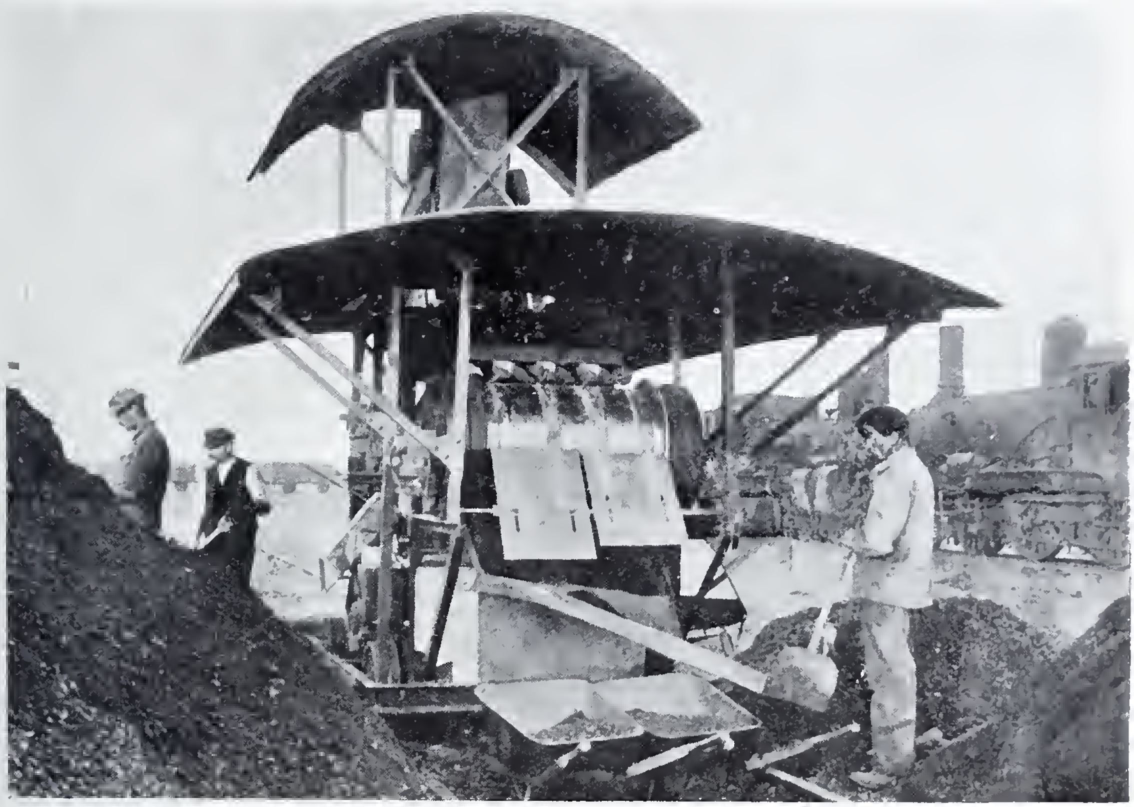


Fig. 78.—The Krupp Magnetic Separator, Portable Type, treating Locomotive Ash for the Hungarian State Railways.

material, some of which were of far greater value than under normal conditions. In a previous chapter it has been observed that from $2\frac{1}{2}$ to 3 million tons of cinders per annum are collected with house refuse in Great Britain. Having in mind that the method of refuse disposal still practised by the greater proportion of local authorities in Great Britain is to tip or dump the refuse as collected on waste land, it follows that the bulk of the fuel which might be recovered and utilised is now wasted.

While it is not possible to check or verify the accuracy of the figures quoted, there can be but little doubt that they are approximately correct. This is to some extent confirmed by the analyses given in Table No. 29, and by similar analyses which have been made from time to time.

Among municipalities in England which have adopted salvage and utilisation systems are Sheffield, Barnsley, Eccles, and the metropolitan boroughs of St Marylebone, and Westminster.

At present it is very doubtful whether it would pay to operate such a system if it were not for the proportion of fuel recovered. In other words the recovered fuel represents a greater return upon the standing and capital charges than any other class of material salved.

Recovered cinder even when screened and in a dry condition is an excellent fuel, and while being similar to coke breeze, usually has a higher calorific value—from 10,000 to 11,000 B.T.U.'s per lb.—and contains but little moisture and incombustible. After passing through a breeze washer, and being freed from dust, the fuel is much improved in value.

Washed breeze from the salvage plant of the metropolitan borough of St Marylebone is used for the firing of steam boilers at the borough electricity generating station.

At Eccles, from an average annual collection of 10,687 tons of refuse, no less than 4061 tons of cinders are recovered. The cinder has a calorific value of 10,875 B.T.U.'s per lb., and an evaporation of 6 lbs. of water per lb. of fuel is obtained in connection with two Lancashire boilers at the Corporation Sewage Pumping Station.

In comparison with steam coal costing 20s. per ton, the recovered cinder has a fuel value of 15s. per ton or an annual value of over £3000.

Mr G. W. Willis, the engineer and manager of the Borough of Eccles Sewage Disposal Works, to whom the author is indebted for the above figures, has obtained some remarkable results in steam generation from recovered cinder, and has very clearly demonstrated what may be accomplished in fuel recovery in a town of 45,000 population.

On the basis of the results obtained at Eccles, and assuming that 2 million tons of cinders per annum are now being tipped to waste, the coal equivalent would be $1\frac{1}{2}$ million tons per annum.

The present tendency among the larger municipalities is to very carefully consider the comparative advantages of burning the whole of the refuse as collected in refuse destructors, and alternatively the provision of salvage plant. Hitherto the principal disadvantage of the former system has been the heavy cost of labour involved for operation. With the successful development of mechanical charging, or feeding, and clinkering, this disadvantage no longer obtains.

The choice between the two systems resolves itself into a question of comparative capital cost and *net* operating cost. In connection with the refuse destructor the only asset worth serious consideration is the steam generated from refuse as fuel. Similarly in connection with the salvage system the only asset of importance is the recovered fuel.

Considered from the point of view of fuel value, it is clear from the results obtained at Eccles and elsewhere that the cinder is of much greater value as a fuel when separated, than when burned with refuse.

CHAPTER IX

THE UTILISATION OF WOOD AND MISCELLANEOUS WASTE FOR POWER PRODUCTION

THE production of power in many coalless countries, where difficulties in obtaining supplies, or high cost of transportation render the use of coal more or less prohibitive, has necessitated the extensive employment of wood, as also a great variety of residual waste for fuel.

Many residuals are now gasified in producers with success which could not otherwise be utilised as fuel. Among these being the following :—

Olive refuse.	Mealie cobs.	Granular cork.	Coffee husks.
Rubber seeds.	Monkey nuts.	Cocoanut husks	Grape cake.
Dried manure.	Coffee pods.	Fruit stones.	Sunflower seeds.
Almond shells	Sudd.	Coir dust.	Prickly pears.
Dung cake.	Crushed cotton seeds.	Ground nut shells.	Tea prunings.
Shavings.			

Among other waste which is also being used for steam generation is sawdust, bark, wood chips, jungle timber, rice husks, bagasse, spent tan, etc.

Timber and wood refuse are largely used for power production in many countries, including West Africa, Nigeria, Rhodesia, West and South Australia, Canada, Denmark, Sweden, Finland, and in a large number of lumber mills, in British Columbia, and on the Pacific coast.

In some countries devoid of coal, or where the cost is so high as to prohibit its use, the consumption of timber is very heavy, and as adjacent growth is cleared supplies have to be transported considerable distances at increasing cost.

Ordinary air dried wood usually contains from 20 to 25 per cent. of moisture. Its composition when absolutely dry is approximately as follows :—

Carbon	=49 per cent.
Oxygen	=44 ,,
Hydrogen	= 6 ,,
Ash	= 1 ,,

The calorific value when dry ranges from 7000 to 9000 B.T.U.'s per lb. approximately, as will be seen from the following table, which comprises a variety of British timber :—

Oak	=8316 B.T.U.
Ash	=8480 ,,
Elm	=8510 ,,
Beech	=8591 ,,
Birch	=8586 ,,
Fir	=9063 ,,
Pine	=9153 ,,
Poplar	=7834 ,,
Willow	=7926 ,,

The heat values of different varieties of Canadian dry wood, as compared with United States anthracite coal, was given by the Forest Products Laboratories of Montreal as follows, the calorific value of the anthracite coal being assumed as 13,000 B.T.U.'s per lb. On this basis the equivalent value of one ton of anthracite coal would be given by :—

1·00	cords[1]	of	Birch.
1·20	,,	,,	Tamarack.
1·50	,,	,,	Jack pine.
1·55	,,	,,	Poplar.
1·60	,,	,,	Hemlock.
2·10	,,	,,	Cedar.

In Great Britain wood waste is extensively used for power production in saw mills, wood working factories, and in other industries in which timber is utilised to some extent, such as shipyards, railway wagon works, and match factories.

For the generation of steam from wood refuse, furnaces of various types are used, comprising ordinary hand fired furnaces, of the natural draught type, forced draught furnaces, dutch oven and semi-external furnaces, and also mechanical stokers.

Where the quantity of waste available is small it is often burned in conjunction with coal. In other works having a larger output of wood refuse, this material provides the whole of the power required, and in a considerable number of works it has been found practicable by utilising the wood waste, either in a gas producer or a steam boiler, to provide the whole of the power required, without the use of coal.

[1] One cord=128 cubic feet stacked.

The choice of the most suitable type and arrangement of furnace for the utilisation of wood waste for steam generation will depend upon various factors, such as the character and quantity of the waste material available, the quantity of steam required, and the type of boiler used.

Light and bulky wood waste, such as shavings, small chips, and sawdust, may be most efficiently used in a dutch oven or external furnace charged at the top. Heavier waste may be more conveniently handled in semi-external furnaces, or other furnaces specially designed.

The mixing of wood refuse and coal in an ordinary boiler furnace, while being a convenient means of disposing of small quantities of waste, is not an efficient method, inasmuch as both fuels give much better results when burned independently.

For the utilisation of large quantities of miscellaneous wood waste for steam generation a boiler of the water tube type is most suitable, providing as it does greater furnace capacity, and better combustion conditions, than obtain with internally fired boilers.

Furnaces of the dutch oven, destructor, or semi-external type may be much more conveniently arranged in connection with water tube boilers, than boilers of other types, and provide the most suitable conditions for the continuous charging of considerable quantities of waste.

For the machine firing of sawdust and chippings from wood working machinery, both in connection with Lancashire and water tube boilers and also dutch oven or external furnaces, Henderson's simplex mechanical stoker, which is illustrated in Fig. 79, is extensively used.

With this apparatus, the general arrangement of which will be clear upon reference to the illustration, sawdust and chippings may be collected from the various machines by means of a pneumatic removal system, and conveyed to an overhead hopper arranged to discharge into the hopper of the mechanical stoker. The fuel after passing through the hopper is carried towards each furnace by means of helical rams, driven by a simple arrangement of gear, and is deposited upon revolving impellers, by which it is distributed over the grates. The impellers are in constant motion, by which means a regular distribution of the material is secured, and the delivery of the fuel may be regulated as desired.

Waste, other than sawdust and chips, are fired direct on to the grate by hand, the grate may be either of the stationary or rocking type.

Details of evaporative tests with hog fuel (lumber mill waste), are given in the following Table No. 35. Having in mind the average moisture content, 38 per cent., the average evaporation of 2·84 lbs. of water per lb. of waste from and at 212° Fahr. must be regarded as a satisfactory performance.

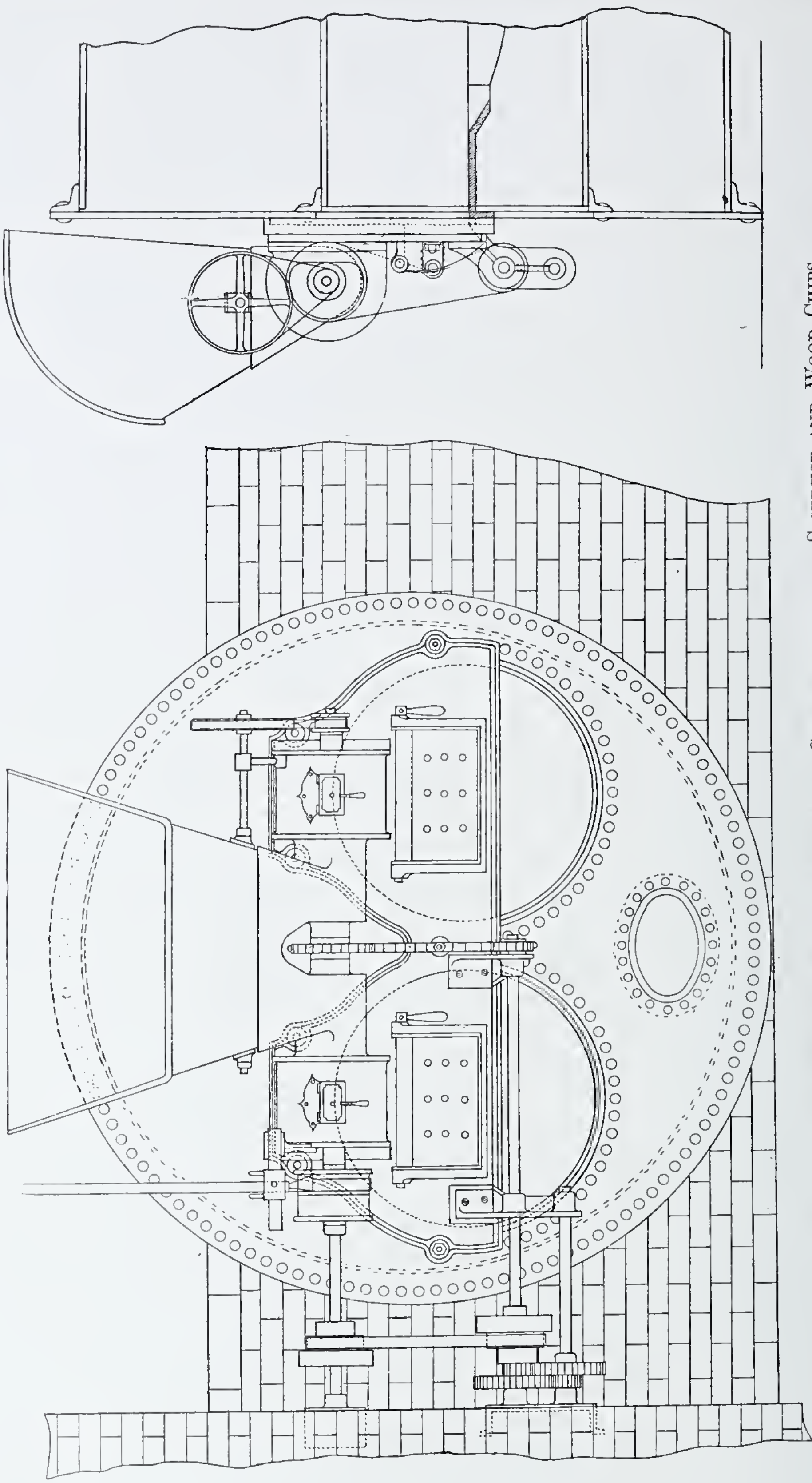


Fig. 79.—Henderson's Simplex Mechanical Stoker for firing Sawdust and Wood Chips.

TABLE No. 35

Evaporative Tests with Hog Fuel and Stirling Water Tube Boilers at St Paul and Tacoma Lumber Company, Tacoma, Wash, U.S.A.

Average calorific value, wet = 5500 B.T.U.'s
" " " dry = 8700 "
Dates of tests—February 20th and 31st, 1917

Furnace—Dutch oven, length in feet			6·5	6·5	
Grate area, square feet			55·25	62·82	
Boiler heating surface, square feet			2617	2878	
Test No.	1	2	3	Average of 1, 2 and 3	4
Duration, hours	8·0	4·0	2·5	14·5	2·5
Kind of fuel	Shavings and Hog.	Hog only.	Shavings only.	..	Shavings and Hog
Steam pressure	131	131	128	130	100
Feed water temperature deg. F.	153	145	143	147	142
Exit gases temperature deg. F.	413	427	430	423	531
Forced draught W.G.	0·2″	0·2″	0·2″	0·2″	0·2″
Average weight of fuel per cubic foot as fired, lbs.	15·32	18·37	14·64	16·11	12·75
Moisture per cent.	38·5	41·5	34·0	38·0	38·5
Calorific value per lb., wet, B.T.U.'s	5506	5253	5593	5451	5506
Calorific value per lb., dry, B.T.U.'s	8953	8979	8474	8802	8953
Cubic feet of fuel burned per hour	375	264	343	339	287
Cubic feet of fuel burned per square foot of grate per hour	3·176	2·236	2·905	2·871	2·431
Total evaporation from and at 212° F., lbs.	127,469	58,737	34,602	220,108	31,311
Evaporation from and at 212° F. per cubic foot of fuel as fired, lbs.	42·5	55·7	40·4	45·7	43·6
Evaporation per lb. of fuel, from and at 212° F.	2·77	3·03	2·76	2·84	3·42
Evaporation per unit, 200 cubic feet of fuel, lbs.	8500	11,400	8080	9000	8720
Boiler horse-power	462	425	401	430	363

Apart from its use for the firing of steam boilers, wood refuse is not utilised to any extent for the firing of furnaces for industrial purposes, although at present in some countries where wood waste is largely used there is a tendency to utilise the same for the firing of furnaces of various kinds.

In Fig. 80 is shown a wood refuse furnace which is used in Vancouver, British Columbia, for the firing of a plate-heating furnace in a large boiler works. This furnace is entirely filled with wood waste, the gases passing downwards through the passages in the side walls commingle with secondary air admitted by piston type dampers on each side, the whole of the gases passing over the bridge wall at the rear.

A constant flow of incandescent gases is ensured through the heating furnace, and no difficulty is experienced in the heating of boiler plates up to $1\frac{1}{2}$ in. thick.

Various attempts have been made to utilise sawdust both alone and also with slack coal, by briquetting, and for this purpose specially designed briquetting plants were installed in British Columbia and on the Pacific Coast. The process would not appear to have proved commercially satisfactory, and so far as the author is aware is no longer used.

In the *Fuel Economy Review*,[1] of February 1922, an exceedingly interesting description was published of a wood refuse gas plant at the timber mills of Messrs J. Sadd & Sons, Maldon, Essex. This plant, as originally installed in June 1910, comprised two sets of 100 H.P. Crossley waste wood refuse gas plant, and two

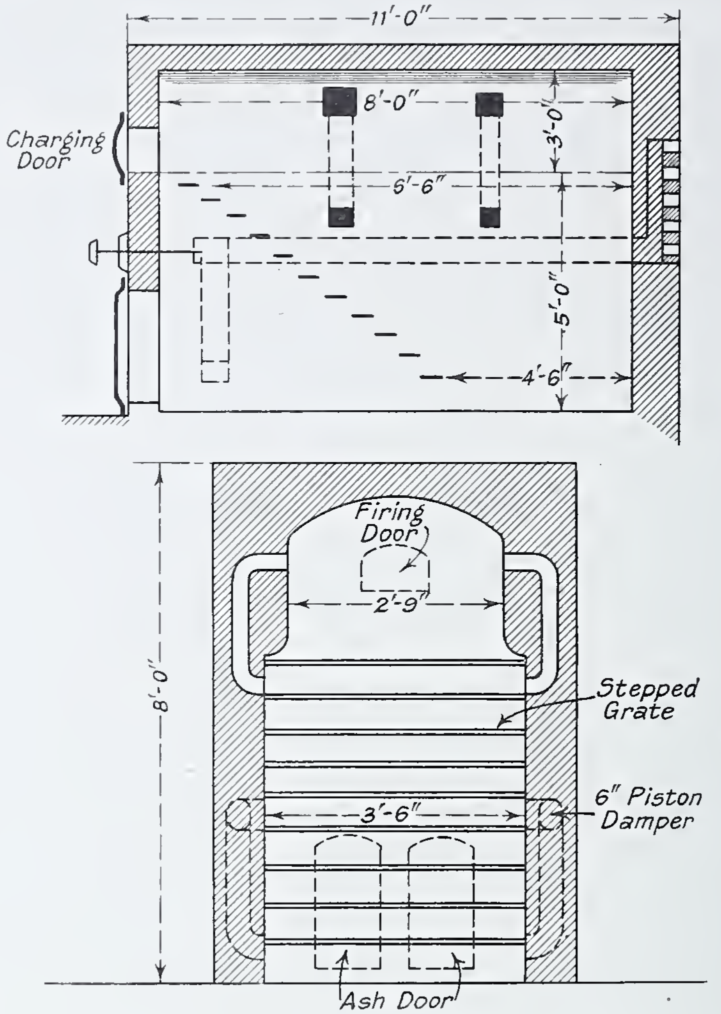


Fig. 80.—Wood Refuse Furnace for Boiler Plate Heating (Vancouver, B.C.).

100 H.P. Crossley horizontal single cylinder gas engines, direct coupled to Crompton dynamos, generating current at 200 volts.

During recent years much additional plant has been installed, comprising in gas producers a 100 H.P. Salmon & Whitfield set, a 300 H.P. Crossley set, and a 250 H.P. Ruston & Hornsby set. In addition, one 250 H.P. Dowson & Mason plant, and one 150 H.P. national producer were installed as stand-by plant. The additional gas engines installed comprised one 120 H.P. Kynoch horizontal single cylinder engine direct coupled to a Crompton dynamo, one 250 H.P. Crossley four-cylinder vertical engine direct coupled to an E.C.C. dynamo, and a 500 H.P.

[1] *Fuel Economy Review*, February 1922.

Premier four-cylinder horizontal engine, rope driving an English Electric Company's dynamo.

For the utilisation of the exhaust in connection with the latter engine, a Ruston & Hornsby waste heat boiler was installed which supplies steam to heat a timber-drying kiln.

The plant referred to not only supplies some fifty motors in the mills aggregating 668 H.P., but current is also supplied both for lighting and power purposes to the town of Maldon and the adjoining village of Heybridge. During the year ending April 30th, 1921, the miximum load recorded at the generating station was 475 kw., and the quantity of electricity sold amounted to 998,364 kw. hours. The fuel consumed in the producers was 2876 tons, comprising 1015 tons of scrap wood, 740 tons of sawdust, 545 tons of chisellings, and 576 tons of bark.

One of the most striking examples of the displacement of a steam plant using wood fuel by a gas producer plant using precisely similar fuel, is at the Lonely Mine, Southern Rhodesia, forty-three miles from Buluwayo.

At this mine, owing to its location—some forty-three miles from the nearest railway connection—the use of coal for steam generation could not be considered owing to the heavy cost of haulage, and it was decided to use wood from the local bush.

So heavy was the consumption of wood during the eleven years' use of the steam plant that the bush had been cleared for a radius of about eleven miles, and had the consumption continued at the same rate for a further three years the economic limit in cost would have been reached. The cost of wood had in fact become one of the most serious factors in the cost of mining.

The consumption of wood for steam generation was at the rate of 3000 cords per month, a cord averaging 3300 lbs. in weight. As the result of installing the Crossley gas producer plant, the consumption of wood was reduced to about 600 cords per month, or approximately one-fifth of the previous fuel consumption.

The complete Crossley producer plant is illustrated in Fig. 81, which is a plan and cross section of the power house, and comprises four Crossley wood fuel suction gas plants, each of 350 H.P. capacity, but capable of giving an overload up to 450 H.P.

The four gas engine sets were supplied by the Premier Gas Engine Company, Ltd., all being of the horizontal multi-cylinder type, the cylinders being of $17\frac{1}{2}$ in. bore, with a stroke of 26 in. Three of the engines drive three-phase alternators, each of 250 K.V.A. capacity at ·8 p.f., with 525 volts at 187·5 revolutions per minute. The alternators were supplied by the South African General Electric Company, Ltd.

The gas engines are designed for 300 B.H.P.[1] normal load, and will carry a 25 per cent. overload. The fourth engine develops 225 B.H.P.[1] at 190 revolutions per minute, and is connected through a flexible coupling to an Ingersoll Rand air compressor, having a capacity of 1500 cubic feet per minute.

The gas generators are charged from a large overhead platform, from which the wood fuel is fed into the hoppers. The wood used is about 10 in. diameter, and is cut into pieces about 2 ft. in length. The feeding hopper, mounted at the

[1] At altitude of 4200 feet, and at reduced speeds to suit alternators.

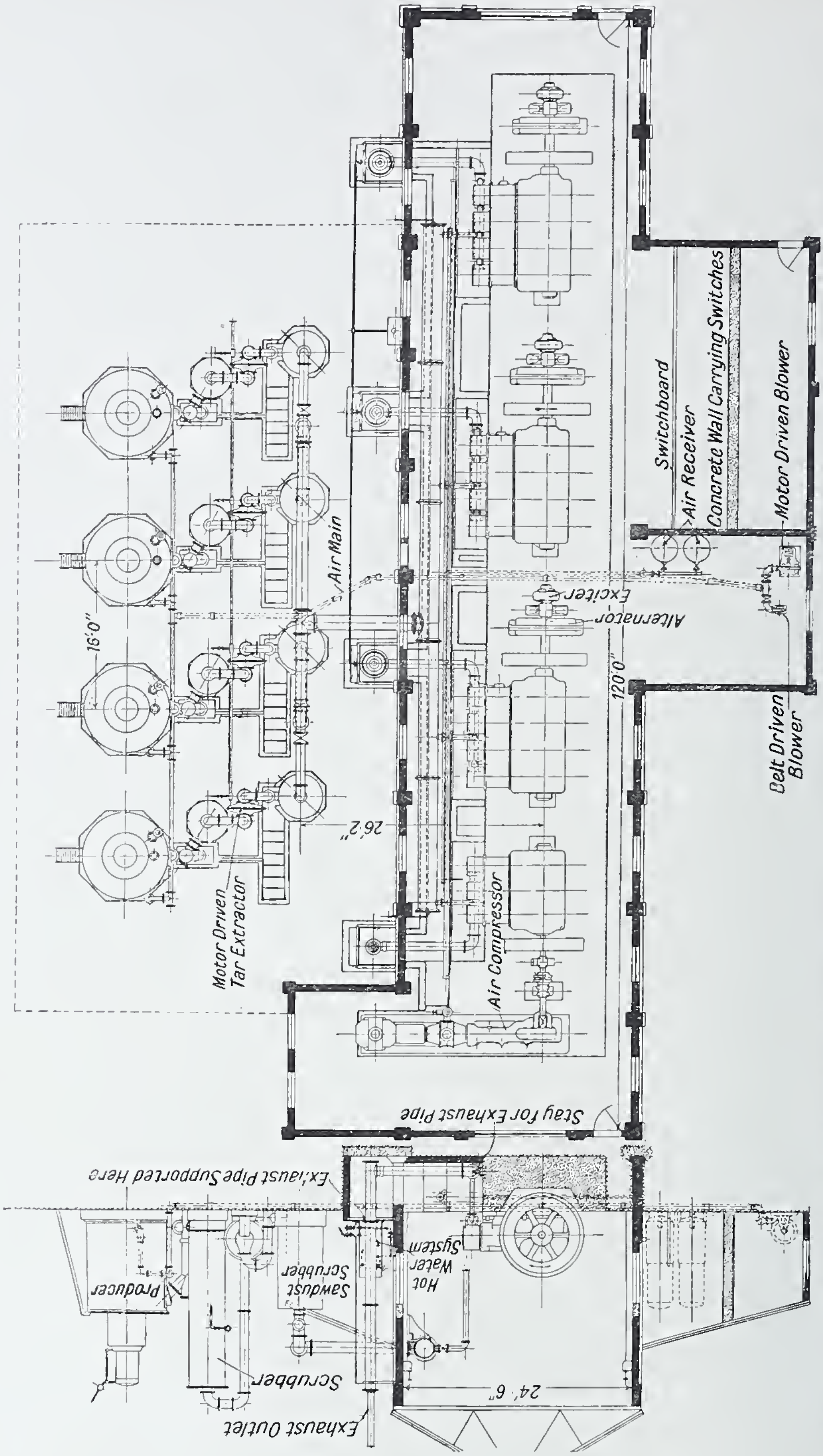


Fig. 81.—Plan and Cross Section of Power House, Lonely Mine, Southern Rhodesia. Crossley Wood-fired Producer Plant.

top of each generator, is of the air lock type. The hot gases as they leave the generator first pass into a wet scrubber, where they are washed and cooled. Within this wet scrubber much of the tar coming over with the gas is condensed and carried away by the cooling water into settling tanks, where it collects and is afterwards removed. The effluent water ultimately flows away in a comparatively clean state.

The question of operating the alternator sets in parallel with each other received very careful consideration by the manufacturers. The gas engines, being of the four-crank type, were easily capable of fulfilling the required conditions, being designed to give a degree of cyclic irregularity not exceeding 1/500. To ensure this degree of steadiness under all conditions of operation, a uniform quality of gas must be supplied to the engines. For this reason a special arrangement of equaliser pipes was introduced between the dry scrubbers of the gas-producing plant, providing for the scrubbers being first coupled together in pairs by means of overhead pipes, which pipes in turn are coupled together and lead into one common main delivery pipe. This arrangement is interesting as showing the means adopted for thorough mixing of the gases after they leave the dry scrubber. A further point is that the suction from each of the gas engines when in operation is more evenly distributed, with the result that each gas generator responds to its fair share of the load and generates gas in proportion.

The installation was tested by Professor Buchanan, B.Sc., of Johannesburg. The following particulars and data have been extracted from his report, dated February 21st, 1922 :—

The main object of the tests was to determine the quantity of dry wood fuel consumed within the plants in generating one Board of Trade unit of electricity. A 24 hours' continuous test was made first working under normal conditions, but only using two producers, these being sufficient to serve the three 200 kw. gas engine alternator sets. The fourth engine, which is used for driving the air compressor, was not tested, one of the gas producers being coupled up to serve this engine exclusively during the test. The fourth producer was shut down entirely throughout the tests.

Care was taken to note that the amount of fuel within the producers was the same at the beginning and finish of the test. The wood fuel used was a normal mixture of mapani, knobby thorn, marula, and other soft woods.

Details of Tests

Date of test	February 2nd and 3rd, 1922
Duration of test	24 hours, 13 minutes.
Total units generated, measured at the switchboard	11,530 units.
Average load from three sets	477 kw.
Load factor (say 160 kilowatts per set) . .	80 per cent.
Corresponding power developed by each engine (89·5 per cent. alternator efficiency) . .	239 B.H.P.

Total wood fuel used during test . . .	41,208 lbs.	
Fuel used per hour	1,703 lbs.	
Fuel consumption rate at 80 per cent. load . .	per B.P.P.	per kw.
	2·39 lbs.	3·575 lbs.
Average moisture content in fuel . . .	13·5 per cent.	
Equivalent dry fuel consumption at 80 per cent.	per B.H.P.	per kw.
load	2·07 lbs.	3·09 lbs.

The makers' guarantees given with dry wood fuel were as follows :—

	Lbs. per B.P.P. Hour.
At full load	2·0
At three-quarter load	2·23
At half load	2·76
At quarter load	3·9

A curve made from the makers' guarantees shows that at 80 per cent. load the

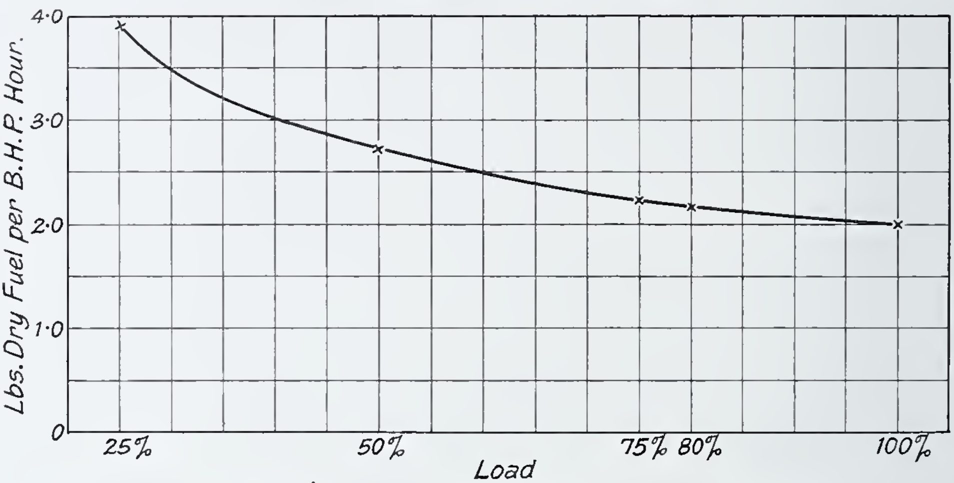


Fig. 82.—Makers' Guarantee Curve for Wood Consumption, Crossley Producers, Lonely Mine, Southern Rhodesia.

corresponding fuel consumption would be 2·15 lbs. of dry fuel (see Fig. 82). As may be seen therefore the actual test result is 4 per cent. below the guarantee.

Assuming an average weight of 3300 lbs. of wood per cord at an average price of 15s. per cord, and taking the fuel consumption to be say 3·6 lbs. per kw. generated, the cost works out at less than 0·20 pence per unit for fuel.

The Ruston refuse gas producer, which has been extensively adopted for the utilisation of wood waste and a considerable range of waste or refuse fuels, is illustrated in Fig. 83, and may be briefly described as follows :—

The fuel chamber provided is of large capacity, with a view to avoiding the necessity for frequent charging. For wood fuel no hopper with a valve or slide is provided, the fuel being fed direct into the fuel chamber.

The generator is of heavy steel plates, lined with firebrick and packing. Doors are provided in the casing for cleaning the fire. The grate is made up of loose fire-bars, which can be removed and replaced through the fire doors. Poking holes are provided so that any part of the furnace can be reached.

Instead of leaving the generator by the usual single outlet, the gases are taken off at two or more points on top of the generator by means of vertical pipes which lead into main pipes, which are inclined to the dust collector. These outlets are so

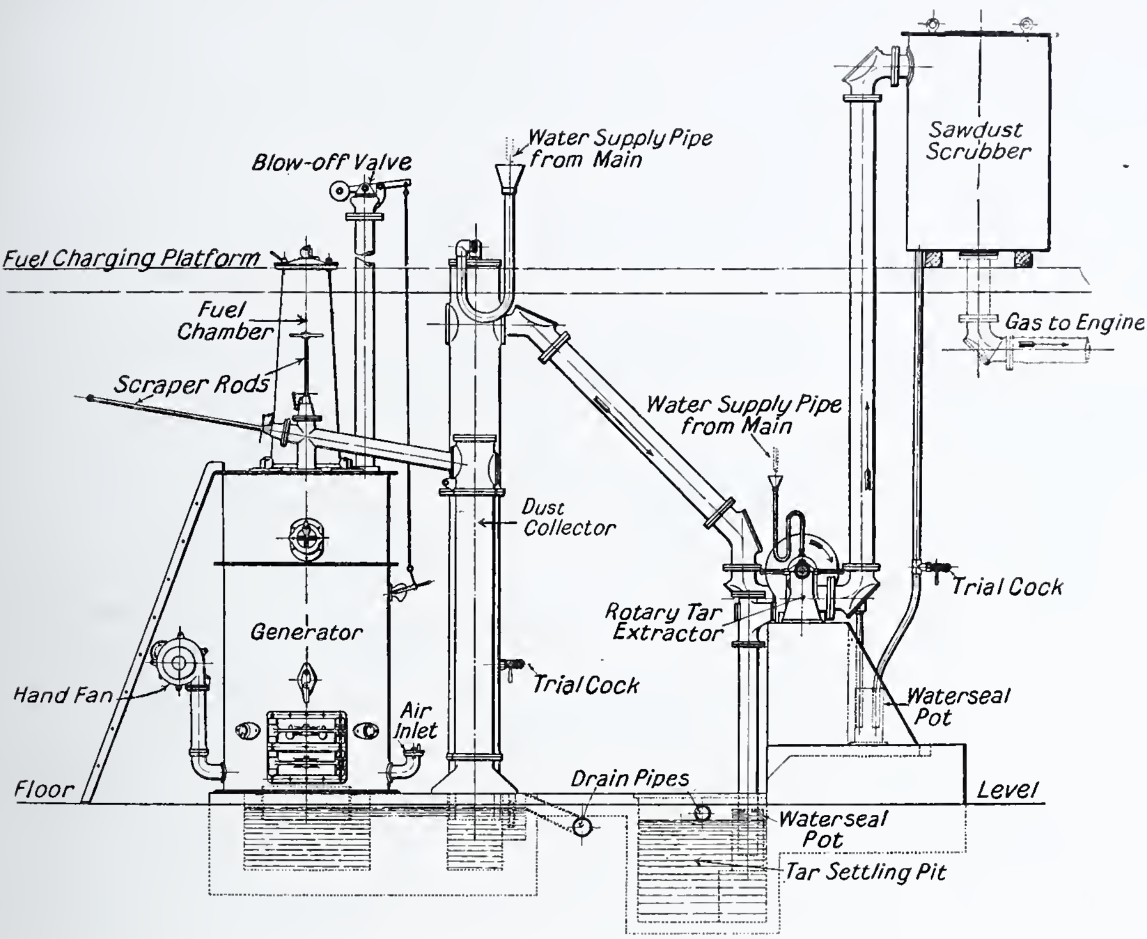


Fig. 83.—The Ruston Refuse Gas Producer.

arranged that an even draught through the fuel bed at all loads and at all points is ensured.

The outlet pipes from the generator are fitted with scrapers by which tar and dust deposits can be removed at any time without interfering with the production and supply of gas. From the top of the dust collector the gas passes to a two-stage rotary tar extractor, where the tar is removed before the gas passes into the sawdust scrubber.

For cleaning and cooling about 6 to 8 gallons of water per B.H.P. per hour are required. Most of this water may be used in cycle, if a filter sump and

circulating pump are provided, but there should always be available at least one gallon per B.H.P. per hour of fresh, clean, cool water.

When using wood refuse, peat, etc., a vapouriser is not necessary. For the use of anthracite or coke it is of course necessary to fit a vapouriser to the generator, as also a double valve hopper to the fuel chamber inlet.

Two important features of the Ruston refuse gas producer are the dust collector and gas washer, and the sawdust scrubber and expansion chamber. These are

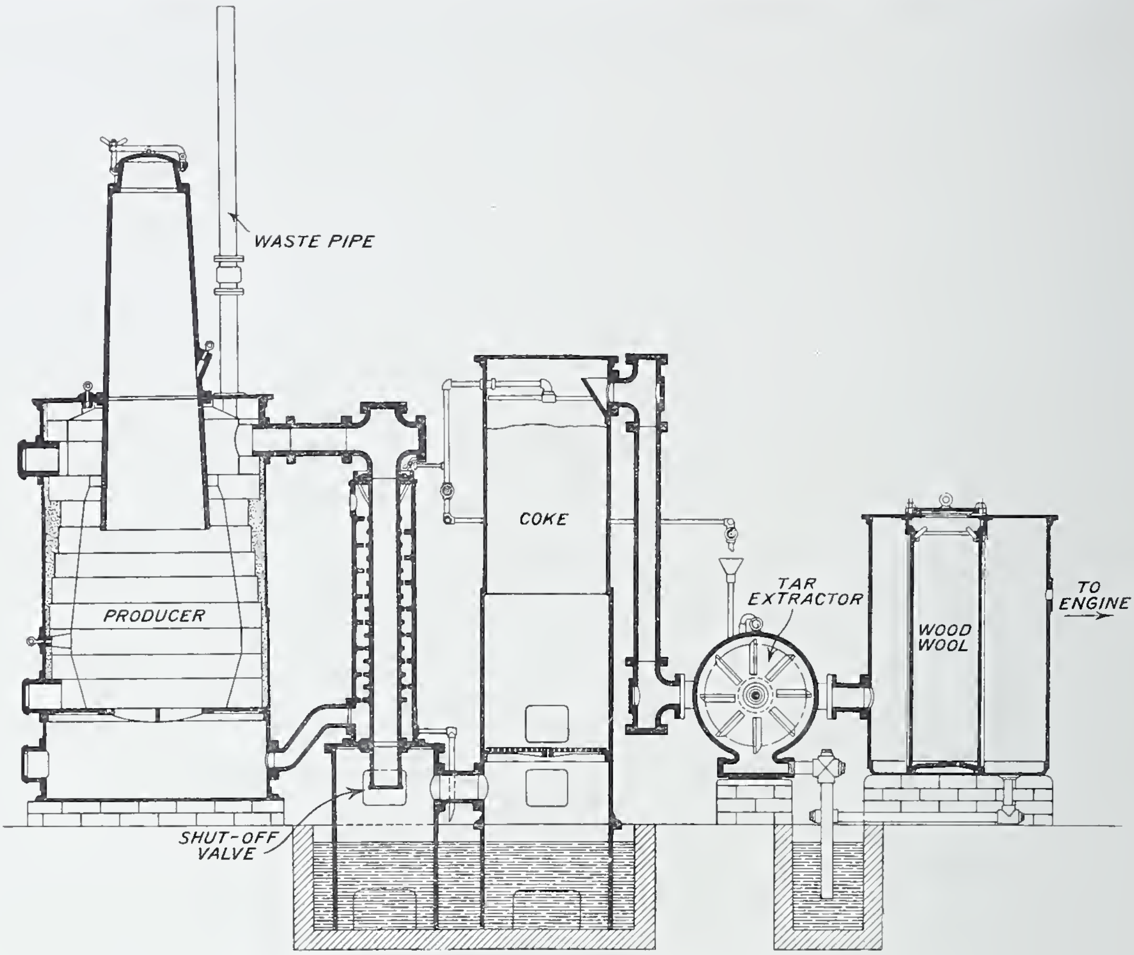


Fig. 84.—The Campbell Refuse Gas Producer.

shown in the accompanying illustration, Fig. 83. It will be observed that the main outlet pipes from the producer lead to the gas washer and dust collector. Here the gas first passes down side tubes and then up a central chamber, where it is cleaned and cooled by a water spray. The dust and a large proportion of the tar in the gas are deposited in a water seal at the base, and may be removed while the plant is in operation.

The sawdust scrubber forms an expansion chamber, and is fitted with trays containing sawdust, acting as a filter. Here the gas is finally cleaned.

The Campbell suction plant for refuse fuels is illustrated in Fig. 84. This producer is largely used for the gasification of wood refuse of every kind, com-

prising sawdust, shavings, chips, bark, etc., also for a great variety of vegetable refuse, such as rice husks, olive refuse, cork refuse, sunflower, and cotton seed husks, cotton stalks, prunings from tea gardens, nut shells, spent tan, wattle bark, bagasse, and flax refuse.

The general working principle is the same as in the older types of suction producers. The gas engine sucks air through a mass of incandescent fuel, converting it into carbon monoxide (CO). This gas with the hydrogen and other fixed gases in the final product are all combustible and suitable for use in gas engines.

The richness of the gas is dependent upon the carbon content of the fuel, and as all refuse fuels are so much lower in calorific value than anthracite or coke, the producer must, therefore, be larger for a given horse power.

In general design, as usually arranged, the Campbell plant comprises a cylindrical riveted steel plate producer lined with firebrick, a dust separator, through which the gas passes to the scrubber, provided with lutes in the sump to enable the separator to be cleared without interfering with the operation of the plant. A wet scrubber of large capacity to ensure low velocity of the gas during cooling and scrubbing, a centrifugal washer, and a dry scrubber which also forms the gas box or reservoir. For starting up, a geared hand-driven fan is provided.

As showing the wide range of waste and low grade fuels which can be efficiently gasified, the following are typical analyses of various fuels which are at present being utilised in producers :—

	Fixed carbon.	Volatile matter.	Ash.	Moisture.
Olive refuse	19·15	53·82	8·45	18·58
Grape refuse	22·50	55·80	11·20	10·50
Monkey nut shells	29·30	60·10	0·50	10·10
Rice husks	15·90	54·90	14·90	10·20
Granular cork	20·25	70·95	1·0	7·8
Cotton pod husks	28·66	53·80	0·34	17·20
Spent tan	10·20	29·70	4·30	55·80
Peat	24·75	55·17	1·10	18·98
Lignite (Taupiri, N.Z.)	43·91	38·50	2·48	14·84
,, (Ledger, W.A.)	46·59	31·20	4·06	17·88
Elm sawdust	6·22	35·54	1·14	57·10
Beech sawdust	7·70	51·90	0·70	39·70
Beech chippings	8·88	69·55	0·42	21·15
Locomotive smoke box refuse, or char	58·93	3·11	24·77	12·58

In Figs. 85 and 86 respectively are shown Ruston producers gasifying tea prunings on a Cingalese tea plantation, and coffee husks at a cotton ginning factory.

Rice or Paddy Husks.—This material is extensively used for fuel purposes in rice-growing countries in the Far East, both for steam generation and also in suction gas producers.

FIG. 85.—THE RUSTON REFUSE GAS PRODUCER ON A CINGALESE TEA PLANTATION.

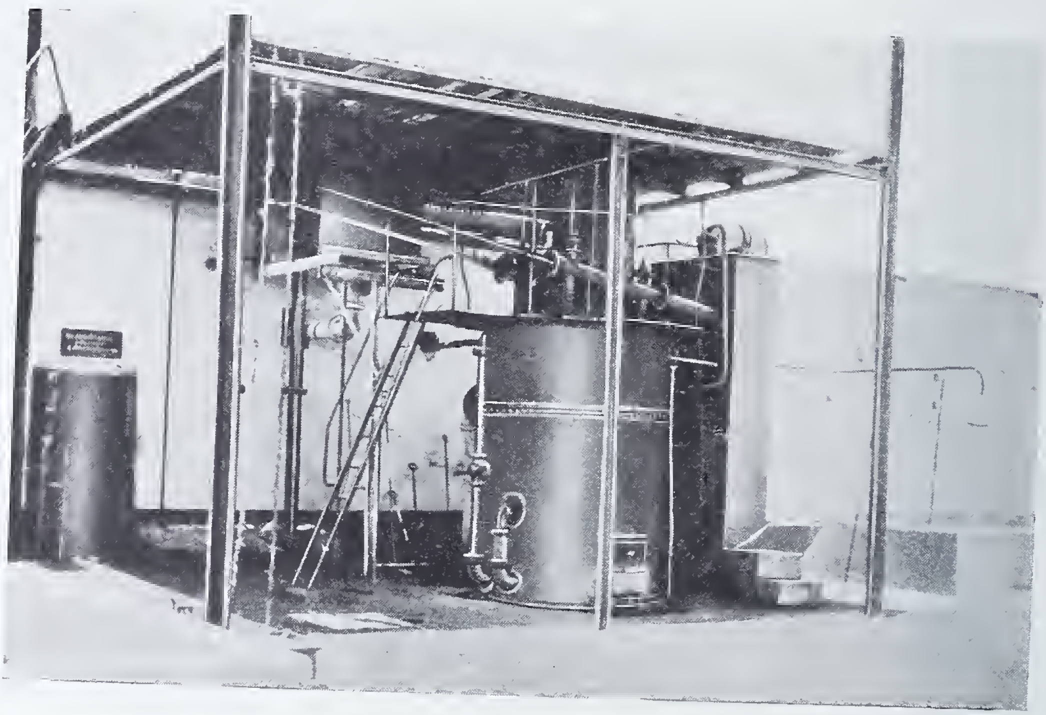


FIG. 86.—THE RUSTON REFUSE GAS PRODUCER AT A COTTON GINNING FACTORY.

Two analyses of rice husks gave the following results :—

	India.	Bangkok, Siam.
Fixed carbon	15·90 per cent.	14·11 per cent.
Volatile matter	54·90 ,,	57·24 ,,
Moisture	10·20 ,,	10·00 ,,
Sulphur	. .	0·05 ,,
Ash	14·90 ,,	18·60 ,,

In some Far Eastern countries paddy husks, despite their bulk and the high percentage of incombustible content, are regarded as a very useful fuel, and in Siam particularly is very very largely used for firing steam boilers both of the Lancashire and water tube types. A very well designed furnace for the firing of paddy husks in connection with a water tube boiler is illustrated in Fig. 87.

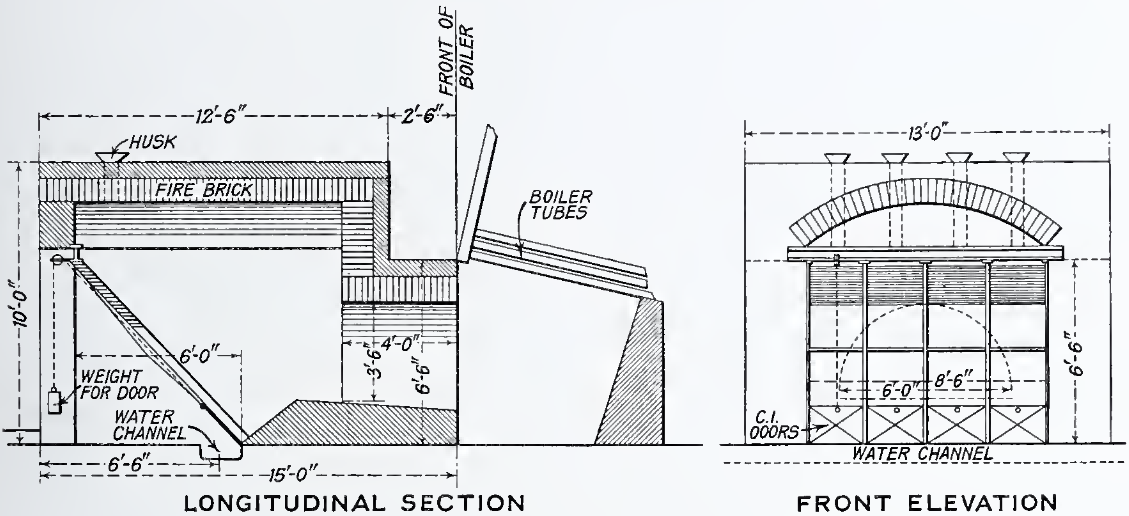


FIG. 87.—FURNACE FOR FIRING PADDY HUSKS IN CONNECTION WITH A WATER TUBE BOILER.

The following results were obtained with a Campbell refuse gas plant and single cylinder horizontal gas engine of 50 B.H.P. at Bangkok, using rice husks, the analysis of which is given above.

Temperatures

Atmosphere=90° Fahr., gas at engine=96° Fahr.

Average load B.H.P.	Average vacuum at engine gas cock.	Gas analysis. CO_2	O	H	CO	CH_4	N	Calorific value.
42	3 in.	3·0	0·4	6·4	32·2	·06	57·4	138 B.T.U.

Consumption=$4\frac{1}{4}$ lbs. per B.H.P. hour.

A Crossley gas plant erected at Amposta, Spain, and utilising rice husks, showed a consumption of rather less than 4·4 lbs. per B.H.P. hour at about two-thirds load, the power requirements being approximately 100 H.P., whereas the plant had a capacity of 152 H.P.

In Fig. 88 is shown a Ruston producer at an Indian ice factory, which gasifies either rice husks or lignite.

Cotton Seed Cake.—Cotton seed and cake has been gasified with complete success in East and Central Africa and also in Egypt for some years past. Mainly in East and Central Africa the British Cotton-Growing Association, Ltd., have been gasifying this material for many years in some sixteen plants, aggregating about 1300 H.P.

Spent Tan.—Spent tan, which consists of the fibrous portion of the bark after use, is approximately 30 per cent. by weight of the original oak bark. When used

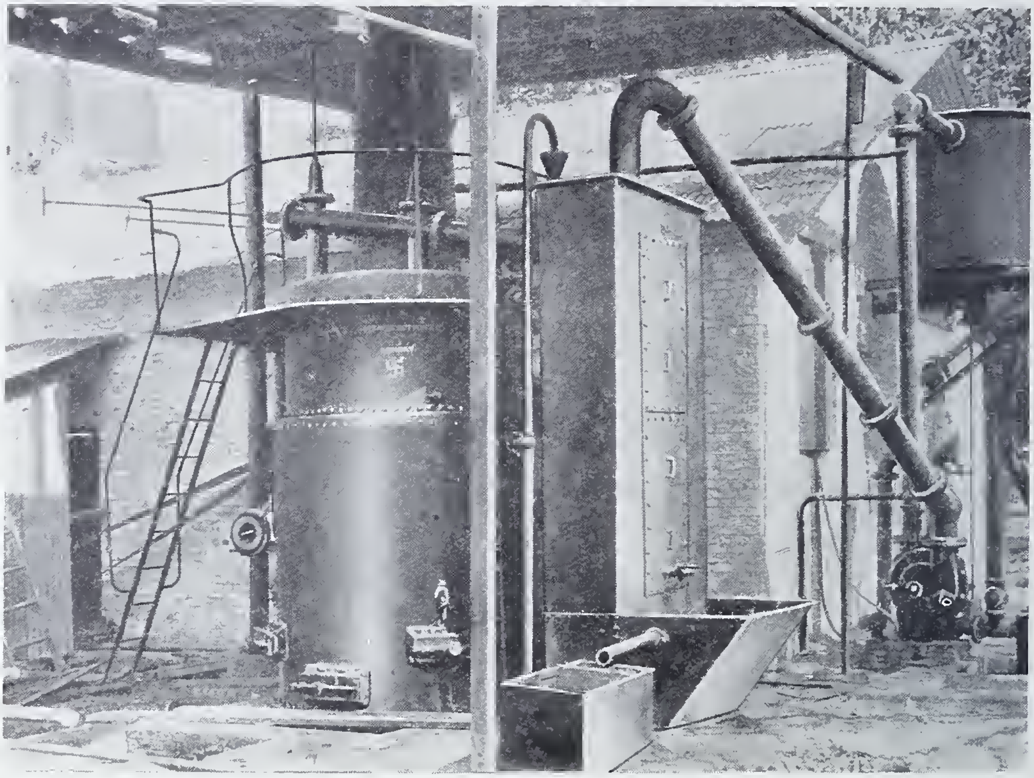


Fig. 88.—The Ruston Refuse Gas Producer at an Indian Ice Factory.

as a fuel it is frequently air dried or pressed. Before drying the moisture content varies from 55 to 65 per cent., and the calorific value from 2600 to 3000 B.T.U.'s per lb. A typical sample analysed gave the following result :—

Fixed carbon	=10·20 per cent.
Volatile matter	=29·70 ,,
Ash	= 4·30 ,,
Moisture	=55·80 ,,

When used for steam generation in a boiler furnace the use of artificial draught is essential, and the tan must also be mixed with small coal or coke breeze. In some large tanneries external furnaces of the destructor type are used in conjunction

with steam boilers. Under such conditions this high moisture fuel is most advantageously burned, and the proportion of slack or coke breeze required is reduced to the minimum.

While considerable quantities of spent tan are used for steam generation, it is also extensively used in gas producers.

Bagasse or Megasse.—This material, which is residual sugar cane, after extraction of the juice, is very largely used for steam generation on sugar plantations. The calorific value of bagasse mainly depends upon the proportion of fibrous matter in the cane. This varies in different sugar-growing countries, but generally speaking is determined by the age of the cane.

FIG. 89.—HAWAIIAN CANE SUGAR MILL.

In Cuba, Hawaii, and the West Indies, the cane is usually left standing for from one to two years, growing to a height of from 6 to 9 ft., and the fibrous content varies from 33 to 50 per cent. In Louisiana, U.S.A., the growth is limited to about six months owing to the climatic conditions. Tropical cane has the greater calorific value, which is usually about 8000 B.T.U.'s per lb.

The crushed cane or bagasse when leaving the last set of rolls in the mill contains from 45 to 50 per cent. of moisture. It is then conveyed to the boiler house, and fed as required into external or dutch oven furnaces, arranged in conjunction with steam boilers. The grates used are of small area, the rate of combustion ranging from 100 lbs. to 300 lbs. per square foot of grate per hour. The whole of the steam required for the operation of the cane mill is usually provided from the bagasse. To a large extent the steam is used for cooking purposes, and out

of the total steam generated about 15 per cent. only is used for power, and 85 per cent. for evaporation and cooking.

As a high moisture fuel the maintenance of a high furnace temperature is essential, and the most suitable furnace is that of the external type, of suitable proportions, lined with firebrick. While good results are obtained when using air at atmospheric temperature, the most efficient results are obtained when using pre-heated air for combustion, or alternatively by reducing the moisture content by pre-drying. For this purpose " secheries " or belt dryers using waste heat are now employed.

A large Hawaiian cane sugar mill is shown in Fig. 89, with cane fields in the foreground.

Blast Furnace Gas.—Both by reason of its low calorific value, which usually ranges from 95 to 105 B.T.U.'s per cubit foot, and also because of the high proportion of dust carried in suspension, blast furnace gas must be regarded as a low grade fuel.

For use in internal combustion engines the gas must be cooled to about 68° F. and thoroughly cleaned. It is necessary to reduce the dust content to 0·1 gramme per cubic foot.

For the firing of steam boilers the gas may be, and is, used in its crude condition, but the serious fluctuation in pressure, as also the large quantity of dust, both present difficulties in its efficient utilisation, and the thermal efficiency obtained is as a general rule very low.

The following is a typical analysis of blast furnace gas :—

CO	=27·5 per cent.
H_2	= 3·0 ,,
CO_2	=10·0 ,,
N_2	=59·5 ,,

B.T.U.'s per lb.=1274

Specific weight at 32° Fahr. lbs. per cubic foot.	Specific volume at Hg cubic feet and 29·92″ per lb.	Theoretical air for combustion, cubic feet per cubic foot.	Theoretical air for combustion, lbs. per lb.	B.T.U.'s per lb.	B.T.U.'s per cubic foot.
08049	12·4329	·729	·729	1274	103

In a paper read before The Iron and Steel Institute on May 5, 1921, entitled " Notes on the Cleaning of Blast Furnace Gas," Mr S. H. Fowles expressed the following opinion :—

" It is possible to-day, if the gas were well cleaned and efficiently used, to produce something in the neighbourhood of from three to four million horse power from the blast furnace gases in this country, in addition to reducing large coal bills, speeding up works, and undertaking much of the work now done by coal fired boilers."

On the Continent and in the United States there has been a tendency towards centralisation, and combination of blast furnaces, by-product recovery ovens, and

steel plant, with a view to the fullest possible utilisation of all the waste heat, and it has been shown that such centralisation effects a very considerable economy in fuel consumption.

In 1911 it was estimated that the aggregate power production by large gas engines, using blast furnace gas, was 1,039,509 B.H.P., distributed as follows :—

Germany	46·5	per cent.
United States	32·5	,,
France	5·4	,,
Belgium	4·6	,,
Austria Hungary	2·4	,,
Great Britain	2·4	,,
Other countries	6·2	,,

In Germany it is the common practice to use cleaned gas for the firing of stoves and boilers, the dust being reduced to about 0·1 gramme per cubic metre. For use in internal combustion engines the gas is usually cleaned and cooled in Thyssen washers, the dust content being reduced to from 0·001 to 0·003 gramme per cubic metre.

Experience in Germany with large installations, comprising in some works many engines from 1500 H.P. to 5000 H.P. each, has shown that clean blast furnace gas is an excellent fuel, and the engines are quite reliable. In some works waste heat boilers have been installed to utilise the sensible heat of the exhaust gas.

Practice in the utilisation of blast furnace gas in Germany is based upon the conclusion that the more the gas engine can be utilised for power and air blast production, the less will be the call upon gas or coal fired boilers, and accordingly the greater will be the economy in fuel consumption from ore to finished steel per ton of product.

Having in mind the very high cost of reconstruction and centralisation in connection with existing works, as also the cost of plant for cleaning the gas, the present indications are that the use of blast furnace gas for firing steam boilers is the most likely line of development, and that the extended use of cleaned gas in the more efficient manner, in large gas engines, is not likely to develop, excepting under favourable industrial conditions, and but very slowly.

At the present time blast furnace gas is extensively used in Great Britain for steam generation, the boilers used being of the water tube, Lancashire, and fire tube types.

As already observed, the thermal efficiency usually obtained is low. This is due not only to the heavy deposit of dust on the boiler heating surface, but also to the difficulty in regulating the air supply in proportion to the gas.

It is very difficult, if not impossible with hand regulation, to ensure at all times a proper mixture of gas and air owing to the continuous fluctuations of the gas pressure and supply. Intimate mixture either before or at the point of combustion is essential in order to obtain the most efficient results.

The use of a combustion chamber lined with refractory material is necessary, and the use of pre-heated air is very desirable, having in mind the small amount of combustible content per cubic foot of gas, and the large volume of gas which has to be dealt with.

In the automatic regulation of the air supply the Weyman system, as installed at the works of the Cargo Fleet Iron Co., Ltd., appears to overcome the difficulties already referred to. This system, which is a simple one, may be briefly described as follows: The apparatus comprises a patent governor, which is actuated by the pressure in the gas main. The governor operates the air ports to the combustion chamber, thus automatically controlling the flow of air in proportion to the gas pressure, and accordingly the volume of gas passing. The governor consists of a tank for the sealing water, in which a bell is suspended by wire ropes over pulleys and balanced by counter-weights. A special feature is the provision in the bell of a central tube in which a vacuum is formed on the bell rising, causing the tube to take up a column of water equal in weight to the pressure on the cross area of the bell. This acts as a dashpot and ensures a very steady movement of the bell in either the upward or downward direction. A rack is fixed to the spindle on top of the bell which is engaged by a toothed quadrant. The opposite end of this quadrant is connected by a horizontal lever to the vertical levers which operate the covers arranged over the air ports in the burner. These covers are mounted on ball bearings.

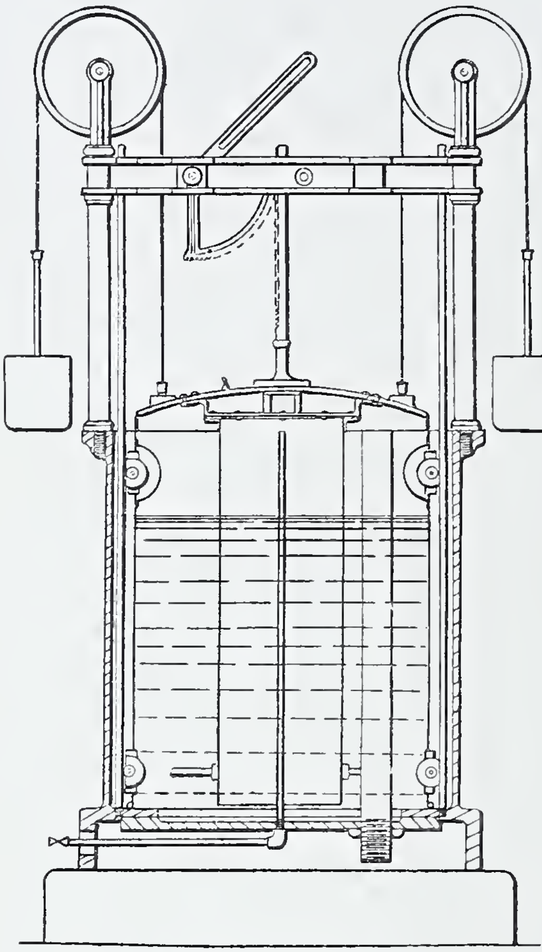


FIG. 90.—WEYMAN'S PATENT AUTOMATIC GOVERNOR FOR CONTROLLING AIR SUPPLY TO BLAST FURNACE GAS BURNERS.

The rise or fall of the governor bell imparts a movement to the quadrant, which movement is transmitted through the horizontal lever to the cover of the air ports, causing them to open or close to a pre-determined degree as the pressure of gas rises or falls. The governor, which is illustrated in Fig. 90, is so sensitive as to control with a gas pressure of only $\frac{1}{16}$ in. W.G.

The burner, which is of the Bunsen type and specially designed for the use of blast furnace gas, is shown in the sectional illustration, Fig. 91. The front end has separate air ports to the body and the central tube. The ball-bearing cover already referred to has similar ports, and on to this disc or cover is fixed a secondary disc,

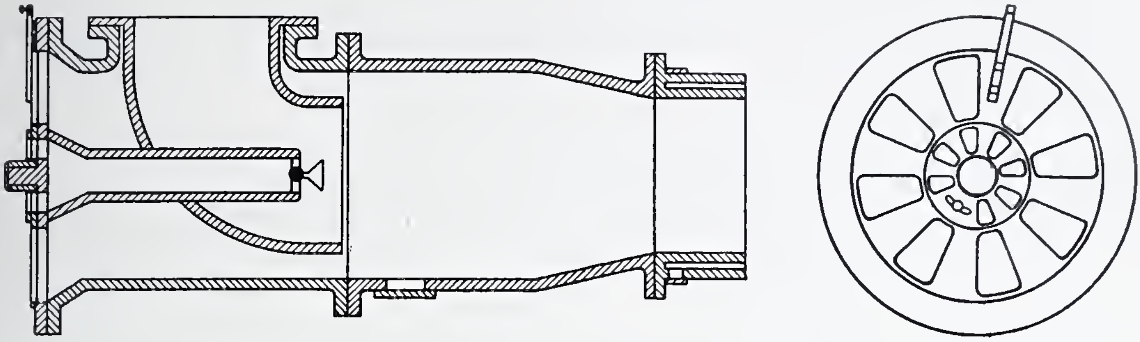


Fig. 91.—Weyman's Blast Furnace Gas Burner.

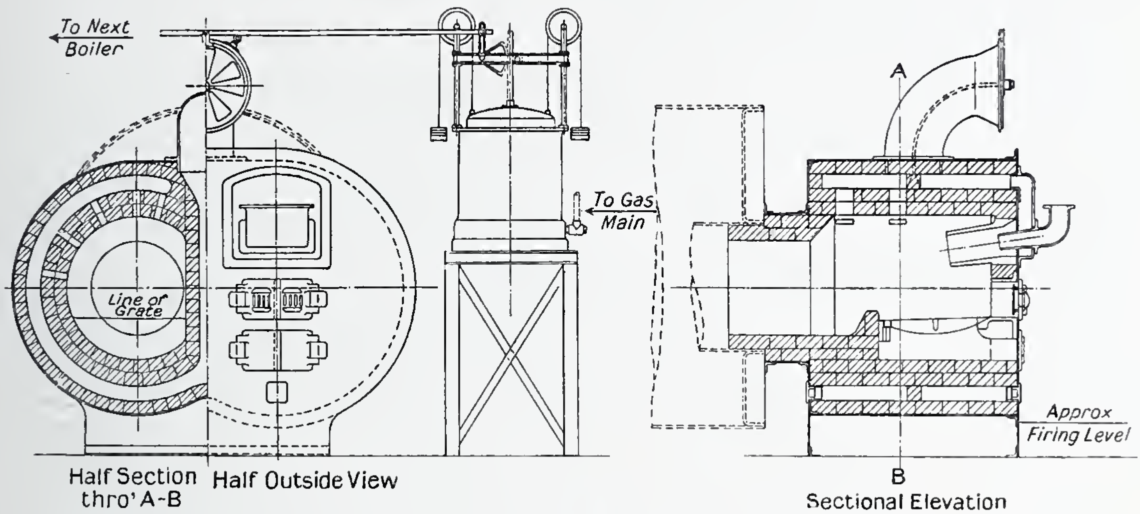


Fig. 92.—Weyman's Patent Combustion Chamber with Blast Furnace Gas Burner, Automatic Air Regulation, and Air Pre-heating Application to a Lancashire Boiler.

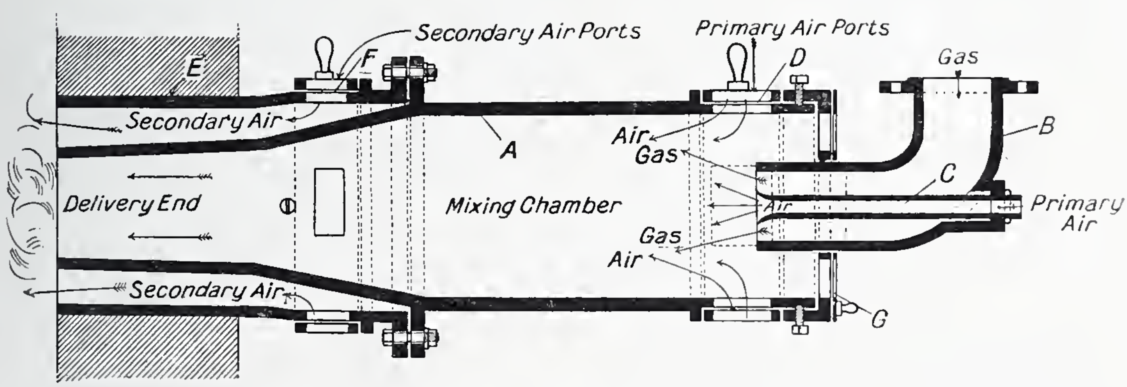


Fig. 93.—The Cumberland Burner.

the ports of which can be adjusted in relation to the main disc so as to permit of the air supply to the central tube being varied in proportion to that passing through the ports to the body of the burner. By adjusting the air delivery through the central tube all tendency to back firing is prevented.

In Fig. 92 is shown Weyman's patent combustion chamber and blast furnace gas burner with automatic air regulation, and air pre-heating, as applied to a Lancashire boiler.

The Cumberland burner, which is illustrated in Fig. 93, embodies in the one apparatus an adjustable gas supply, as also adjustable primary and secondary air supplies, and may be satisfactorily operated with a gas pressure of ½ in. W.G.

The body of the burner is formed of a tubular mixing casing (*a*), which is tapered in such a manner towards its delivery end as to prevent back firing. The gas is

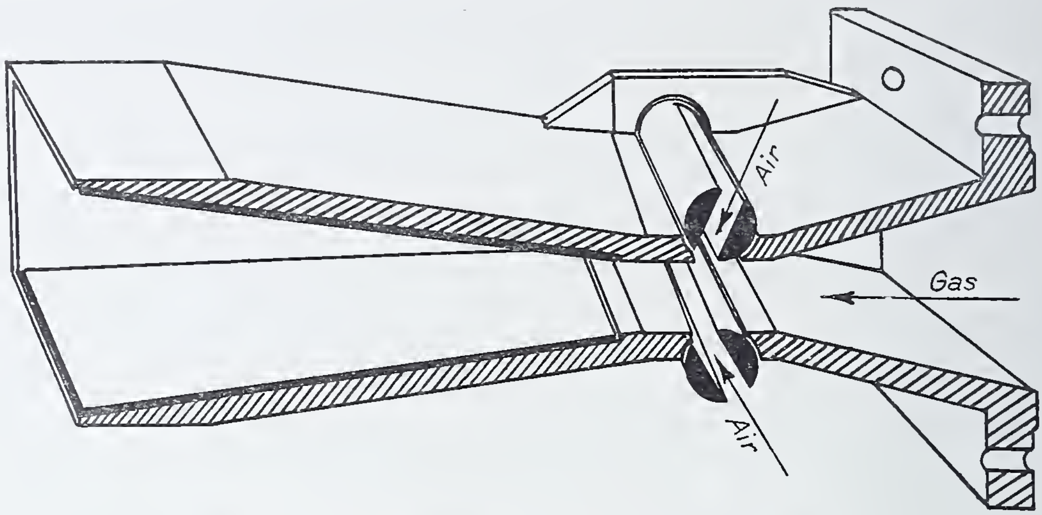


FIG. 94.—THE HUNTER BLAST FURNACE GAS BURNER.

supplied to the outer end of the burner from a vertical connection through the bend (*b*), and the primary air is supplied partially by means of a centrally fixed tube (*c*), which projects through the gas inlet connection, and partially by means of a series of inlet ports (*d*), formed round the end of the burner tube. These latter ports are adjusted in area by means of a rotary sleeve, which is so arranged that the air admission may be very effectively regulated.

The combined arrangement of central and also external air ports provides for a thorough mixing of the gas and air.

Near the delivery end of the burner is a concentrically arranged casing (*e*), in which secondary air ports are provided, similar to the primary air ports (*d*). At the end of the mixing chamber a cover (*g*) is provided, which enables the attendant to control the mixture of gas and air.

In Fig. 94 a sectional view of the Hunter blast furnace gas burner is shown. With this type of burner the primary air is admitted through slotted adjustable rollers. Secondary air as necessary is admitted around the nozzle of the burner.

The application of Hunter blast furnace gas burners to a battery of Thompson water tube boilers is shown in Fig. 95.

In the United States blast furnace gas has been used in conjunction with pulverised coal for the firing of steam boilers, and at least one such combined plant

Fig. 95.—Application of Hunter Blast Furnace Gas Burners to a Battery of Thompson Water Tube Boilers.

has now been installed in this country. This dual method of firing would appear to offer distinct advantages from the point of view of reinforcing a low grade fuel, and increasing the evaporative output, the dust problem must, however, become more acute due to the ash carried in suspension with the pulverised coal.

CHAPTER X

THE GASIFICATION OF LOW GRADE AND WASTE COAL

In gas producer practice a very wide range of carbonaceous materials are now being successfully dealt with. The development of the suction gas plant, introduced rather more than twenty years since, and its successful application for the use of a considerable variety of waste fuels, and residuals, has been of great advantage, not

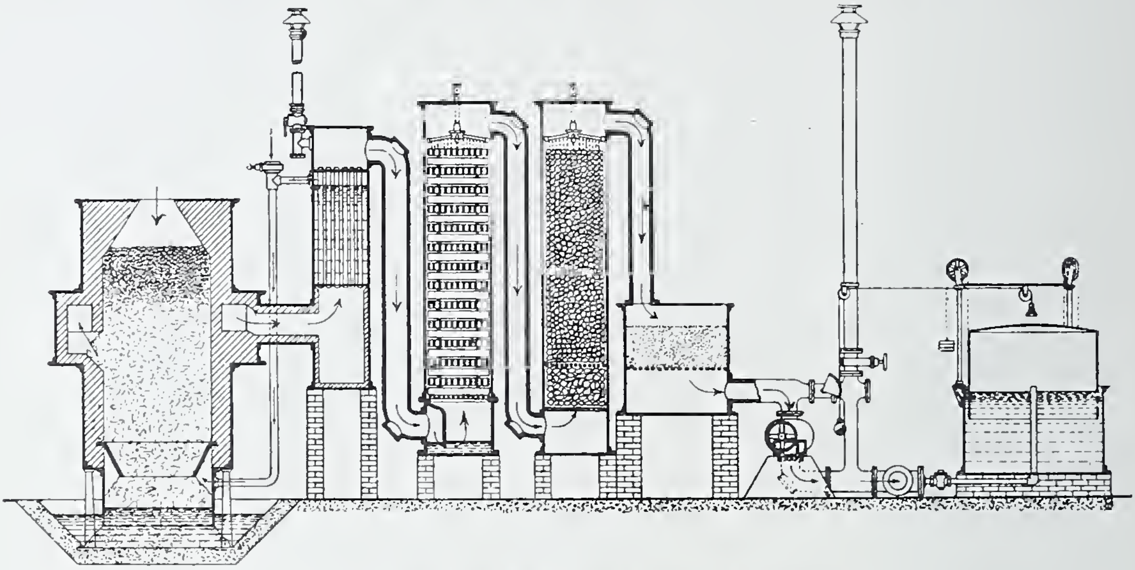


FIG. 96.—THE DOWSON BITUMINOUS PRODUCER.

only in greatly reducing the cost of power production, but also in enabling fuels to be utilised which could not otherwise be employed.

The many waste fuels which are now being gasified in suction producers while widely varying in their composition, are all comparatively low in ash content, and therefore present but the minimum of difficulty in clinker formation with fixed grates.

In its simplest form the suction gas producer is not suitable for gasifying bituminous coal, or for fuels of a caking nature. In specially designed suction plants such fuels are used, as for instance, in the Dowson bituminous producer, in which almost any coal not containing more than from 30 to 35 per cent. of volatile content can be gasified. With this type of plant the tar is converted into gas in the producer.

The Dowson bituminous producer, which is illustrated in Fig. 96, is of the double acting type. *i.e.* air is drawn in through the top, and through the bottom of the fuel column. The producer is open at the top, where it is charged, but there is no

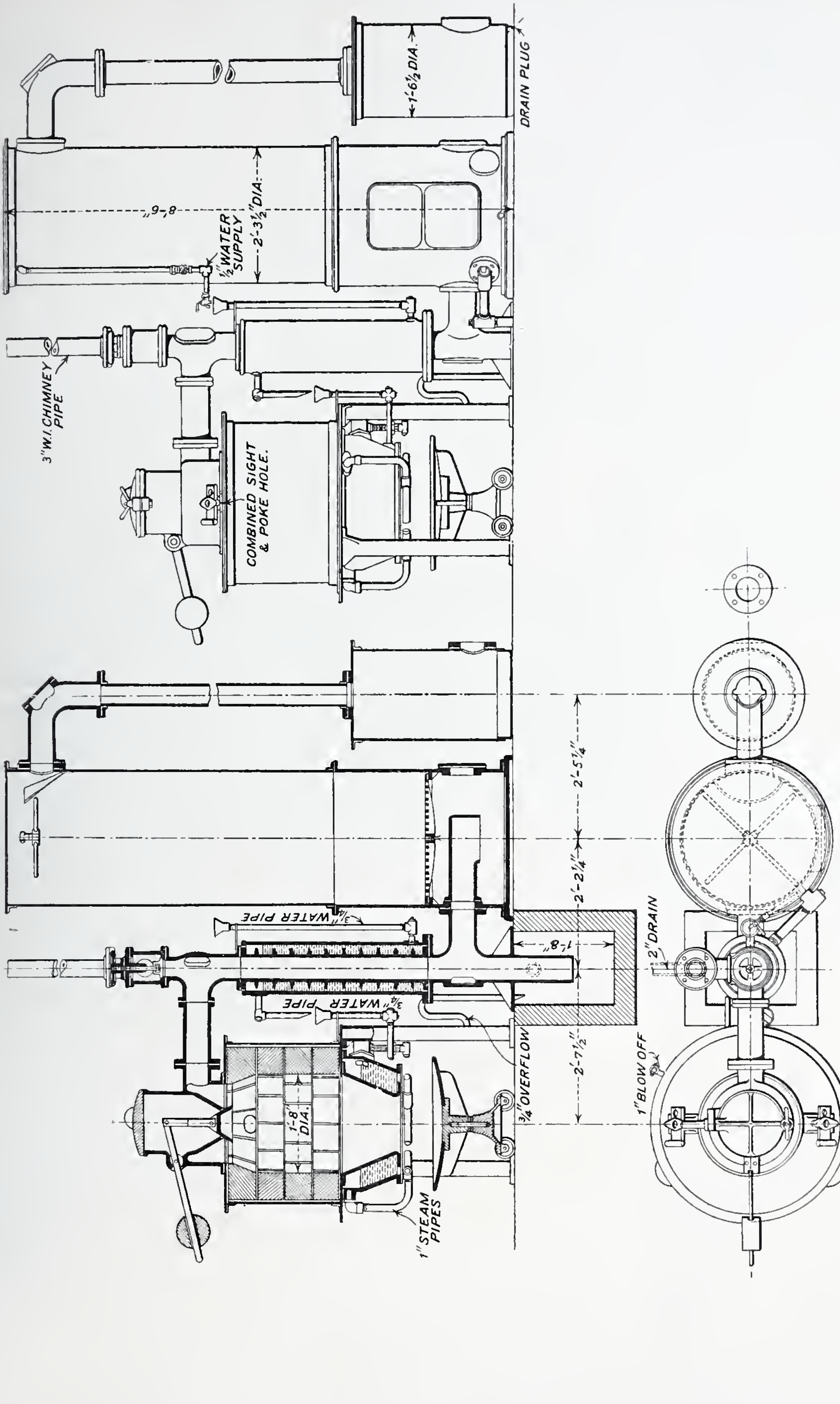


FIG. 97.—THE CAMPBELL OPEN HEARTH SUCTION PRODUCER.

escape of gases, as air is drawn inwards by means of an exhaust fan. The upper part of the fire burns downwards, the hydrocarbons are distilled off, and the coke which remains sinks downwards into the lower part of the producer, where it meets

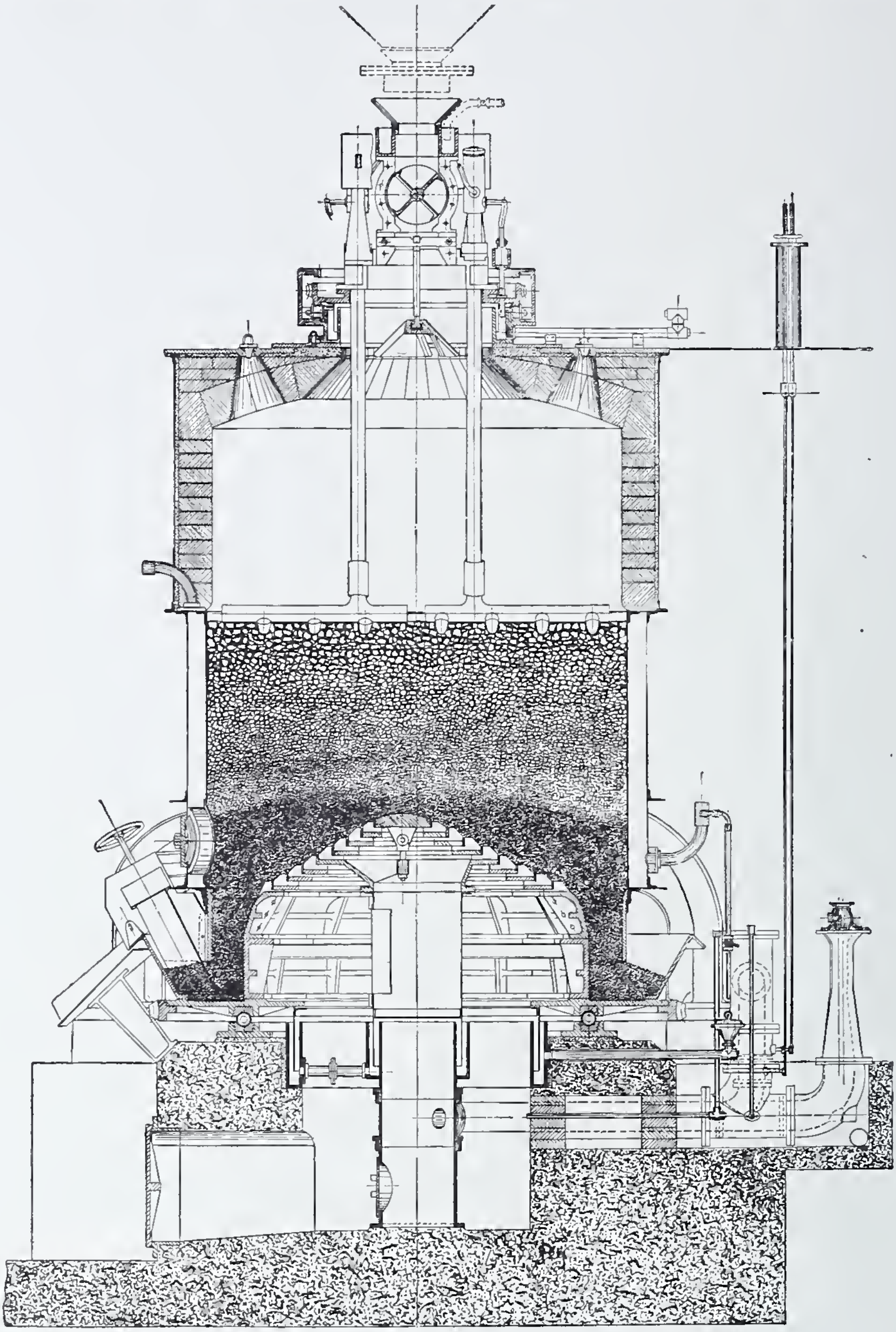


FIG. 98.—THE KERPELY REVOLVING GRATE PRODUCER.

an upwards current of steam and air, and is converted into ordinary producer gas. The mixture of gases leaves the producer through an outlet about midway between the top and the bottom.

The producer has a water bottom, so that clinker and ash may be removed while the plant is in operation. After leaving the producer the hot gas passes through a vaporiser for cooling, and to generate the steam required, thence passing through a water seal, and through special scrubbers to remove dust, soot, etc. In this process there is no tar, and no mechanical or other extractor is required. The

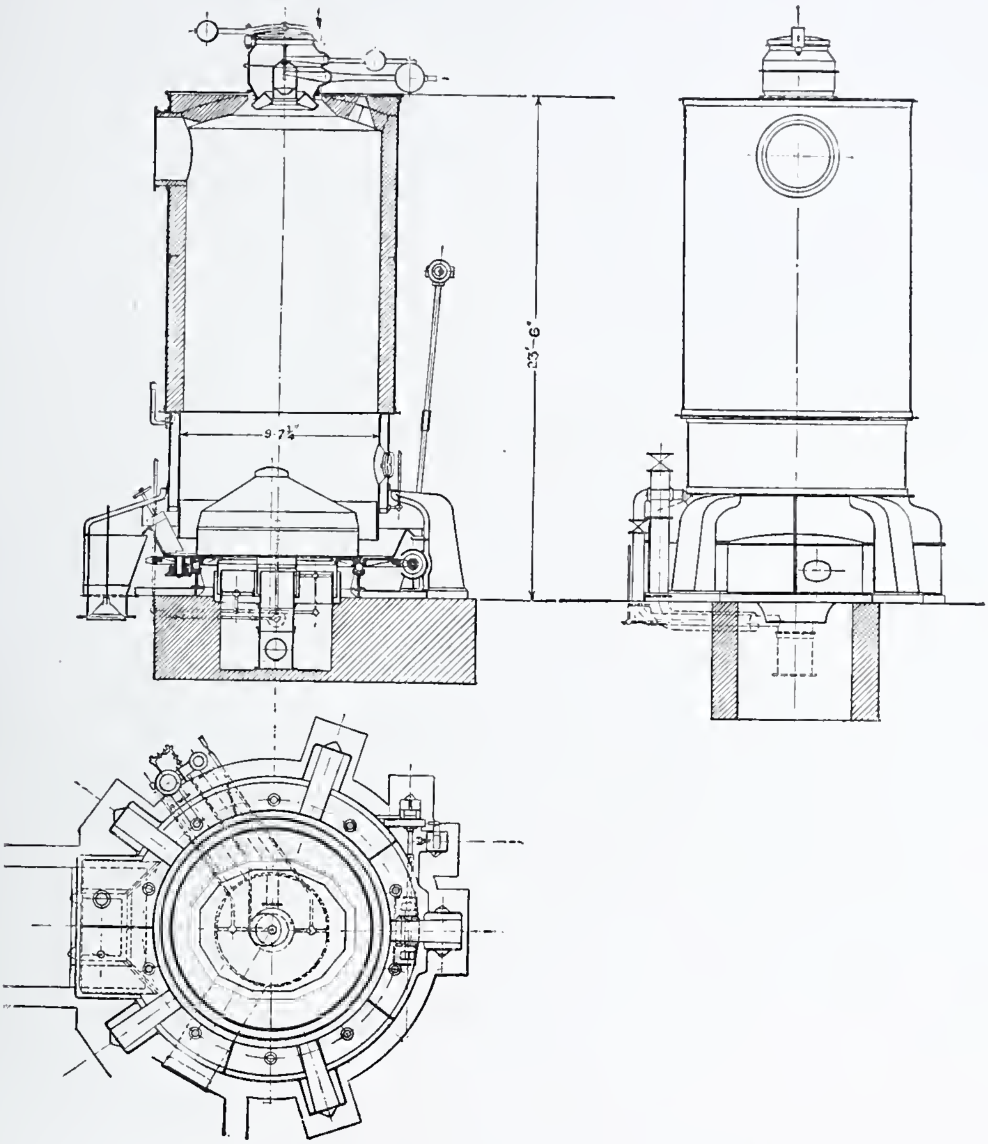


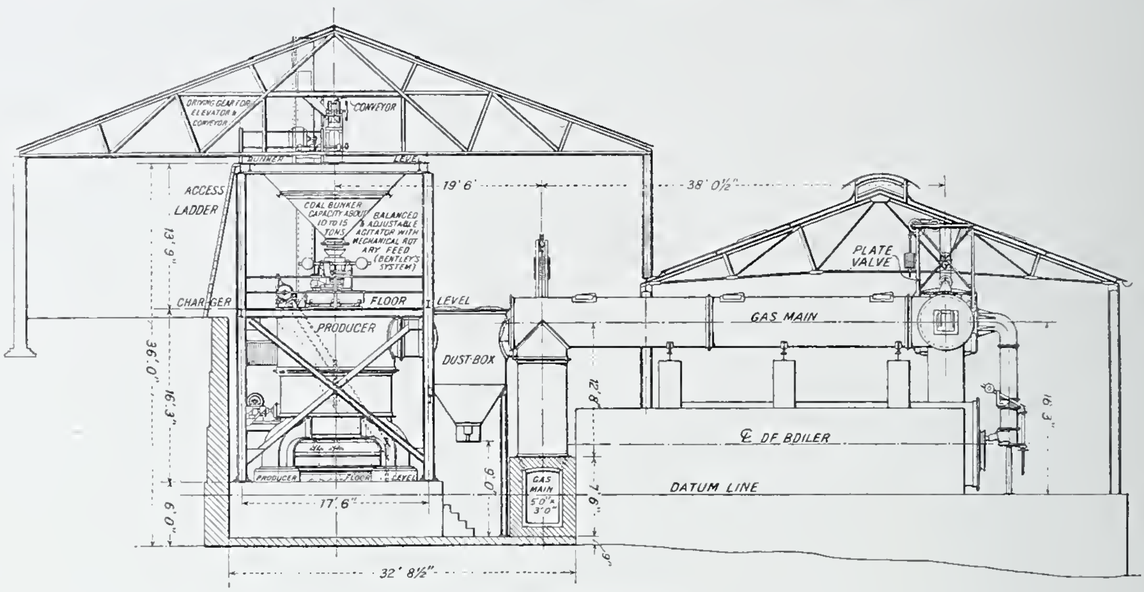
Fig. 99.—Kerpely Patent Revolving Grate Producer for Ammonia Recovery.

Campbell open hearth suction gas plant, which is illustrated in Fig. 97, was introduced in order to gasify certain fuels which could not be satisfactorily dealt with in an ordinary suction producer, such as, for instance, small anthracite and coke breeze slightly over $\frac{1}{8}$ in. in size, and also small locomotive smoke box refuse or char.

The fuel rests upon a solid hearth forming a conical fuel bed, the sides of which are open to the atmosphere, ample area is thus obtained for the introduction of air, and also steam from the evaporator.

It is not possible to gasify these small fuels on an ordinary enclosed grate as usually employed, owing to the very limited air spacing of the grate, the close lying nature of the fuel, and the impossibility of providing sufficient air to support combustion.

The open hearth also provides facilities for poking and the removal of clinker at any point around the hearth, without interfering with the process of gas production.



CROSS-SECTION.

FIG. 100.—ARRANGEMENT OF THREE KERPELY PRODUCERS FOR FIRING A BATTERY OF LANCASHIRE BOILERS. (See also facing page.)

Owing to the position of the evaporator, the wall of the producer next to the hottest part of the fire is kept comparatively cool, clinker does not adhere, and the arching or bridging over of the fuel is avoided.

For the gasification of low grade fuels, and more particularly waste fuels having a high ash content, mechanical and revolving grate producers are now extensively used.

Among the advantages claimed for producers of these types as compared with fixed or stationary grate producers are the following :—

1. The automatic removal of ash.
2. Low labour cost in the handling of incombustible.
3. More uniform and more complete combustion.
4. Operation for long periods without interruption.
5. The gasification of much more fuel per square foot of fuel bed area.

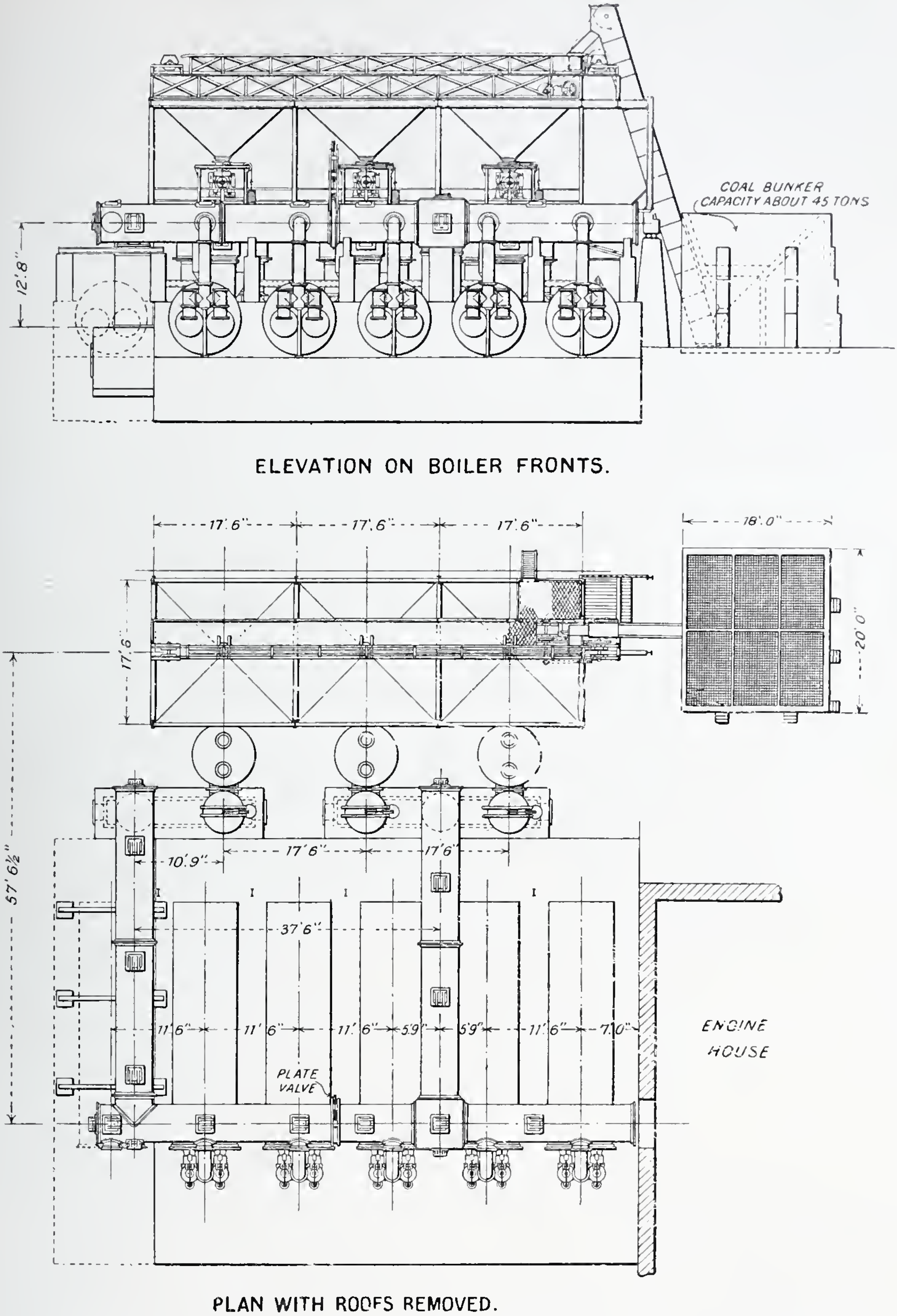


FIG. 100.—ARRANGEMENT OF THREE KERPELY PRODUCERS FOR FIRING A BATTERY OF LANCASHIRE BOILERS.

6. Saving in space per 1000 cubic feet of gas produced.
7. Freedom from dust and dirty conditions during the removal of ash.
8. Production of gas of a uniform quality.
9. Reduction in the cost of maintenance.

Among gas producers of the mechanical type which have been specially designed for the gasification of low grade and waste fuels, are the Kerpely, Stein Chapman, Pintsch, Rehmann, and "G. R.," all of which embody special and distinctive features in design. The Kerpely, Stein Chapman, and "G. R." producers will be described and illustrated.

The Kerpely Mechanical Gas Producer.—The principal features in the design of the Kerpely revolving grate gas producer, combining mechanical rotary feed and distribution, and also balanced and adjustable agitators, are shown in Fig. 98.

The grate is of polygonal shape, and is arranged eccentrically on the water trough. It has a continuous action in crushing any clinker formation. The clinker when entering the ash zone is caught by the numerous edges of the revolving grate, and is pressed horizontally sideways against the seal apron, being broken or crushed into small fragments, which falling into the water trough are removed by the ash scraper.

The ash scraper automatically discharges the ash and clinker accumulating in the bottom of the producer, and being constructed to suit the shape of the ash trough, the ash is not only pushed aside, but is piled up and continuously discharged into an ash shoot.

The water cooled jacket of this producer is a valuable feature in the gasification of clinkering and caking fuels. By means of this provision the use of an excessive quantity of steam is avoided and the poking required with brick lined producers in breaking down the clinker is obviated. The saving in labour and steam, the production of a drier gas, and the prolonged life of the furnace brickwork are all points of importance.

The supply of air and steam to the Kerpely producer is separately delivered to the inner and outer sections of the grate, and passing through the spaces between the plates of the revolving grate ensures uniform combustion over the whole grate area.

Other features of this producer are the central rotary fuel feed and the balanced adjustable agitators. With the former a level fuel bed is ensured, the bed being stirred to the required depth by the agitators.

The speed of the feed can be varied while in operation to suit all working conditions; and a safety device is fitted to prevent breakage of the feed parts, or damage to the motor as the result of iron or other foreign material passing through with the fuel. The drum is easily accessible for cleaning.

The agitators are balanced on ball bearings, and can be adjusted to work at varying depths of agitation, or to float on top of the fuel bed as may be required by the fuel which is being gasified. This adjustment may be made while working.

The agitator fingers or forks are made of a special heat resisting alloy, and while being easily renewable are not water cooled. The agitators may be removed through the top of the apparatus if desired without entirely closing down the producer. The power required for the operation of the agitators is rather less than 1 H.P.

The Kerpely high pressure producer for operation under ammonia recovery conditions is illustrated in Fig. 99. This type of producer is fitted with a patent

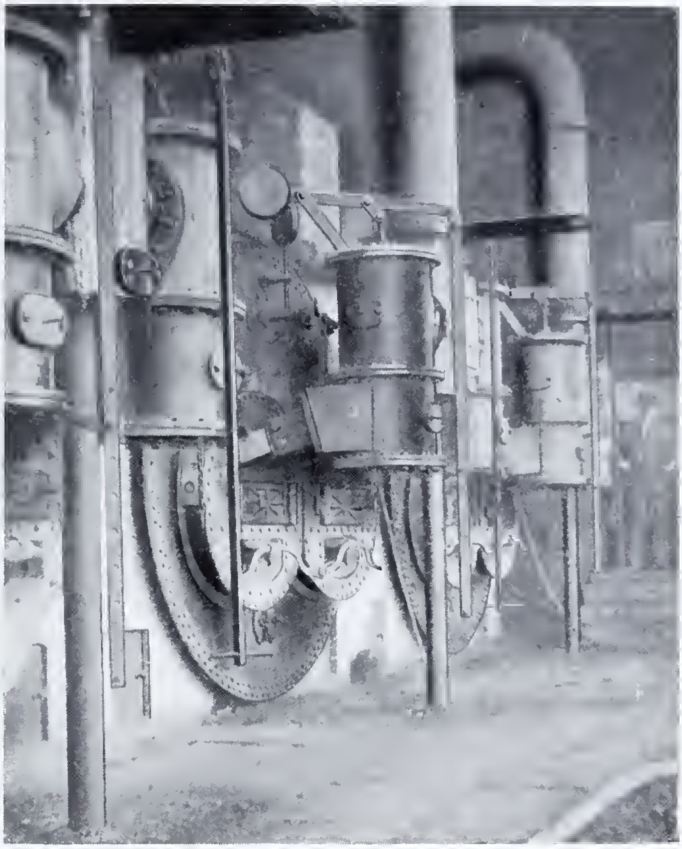


Fig. 101.—Kerpely Gas Valves and Burners for Producer Gas Firing.

enclosed water seal covering the ash pan and revolving grate. This arrangement ensures the pressure of air under the grate, being the same as that above the water seal, so that no deep seal plates are necessary, with consequent difficulties in removing ash. A high pressure producer having a fuel bed diameter of 9 ft. $7\frac{3}{4}$ in. will gasify over 3000 lbs. of fuel per hour.

In Fig. 100 is shown the general arrangement of three Kerpely producers fitted with Bentley's mechanical feed and agitators, gasifying a low grade coal at a Scotch colliery, the gas being used for the firing of a battery of Lancashire boilers. Part of the boiler-house is shown in the illustration, Fig. 101, as also the gas valves and burners.

Daily working analyses, with saturation temperatures, taken from Kerpely producers using Midland producer coals, are given in Table No. 36, while in Table No. 37 complete details of an evaporative test are given as also analyses of the fuels gasified.

TABLE No. 36

Daily Gas Analyses for the month of June 1922, with a Kerpely Gas Producer, with Bentley's Mechanical Feed and Agitators

Date.	Saturation degrees centigrade.	Steam Pressure at Blowers.		Gas Analyses per cent.					Total combustible per cent.	Calorific value B.T.U.'s.	Kind of Coal.
		Outer lbs.	Inner lbs.	CO_2	CO	CH_4	H_2	N_2			
1st	59	25	45	3·4	28·0	3·43	13·10	52·07	44·53	167	Mansfield
2nd[1]	61	20	40	5·4	24·6	3·74	12·46	53·86	40·86	157	,,
3rd	61	20	40	3·2	28·2	3·66	14·18	50·76	46·04	174	,,
6th	56	25	50	3·2	28·4	4·11	13·39	50·90	45·90	177	,,
7th	57	25	50	2·8	29·6	3·63	13·30	50·67	46·53	176	,,
8th	57	25	50	2·6	29·0	3·86	13·93	50·61	46·79	178	,,
9th	57	25	50	3·2	29·0	3·63	13·01	51·16	45·64	173	,,
10th	57	25	50	3·6	28·0	3·45	12·28	52·67	43·73	165	,,
12th	60	20	45	3·8	28·0	3·41	13·50	51·29	44·91	165	,,
13th	62	27	50	2·4	29·2	3·88	13·09	51·43	46·17	176	,,
14th	63	25	50	3·2	28·4	3·42	14·29	50·69	46·11	173	,,
19th	62	25	50	4·0	27·2	3·21	13·46	52·13	43·87	165	,,
20th[2]	62	33	60	4·4	25·2	3·70	13·88	51·82	42·78	154	,,
21st	62	30	40	2·4	29·0	3·66	12·81	52·13	45·47	172	,,
22nd	62	30	40	2·8	29·0	4·38	12·73	51·19	46·11	179	Mansfield Cannock
23rd	60	30	40	3·2	29·0	3·63	12·69	51·46	45·32	173	Great Wyrley
26th	61	30	50	3·8	27·0	3·45	15·28	50·47	45·73	172	Creswell
27th	61	23	45	3·2	27·8	3·71	13·80	51·49	45·31	172	,,
28th	60	30	50	3·6	28·6	3·18	13·01	51·61	44·79	167	Langwith
29th	60	30	50	3·4	27·6	3·45	14·12	51·42	45·17	170	,,
30th	63	35	60	4·0	27·4	4·14	14·92	49·94	46·06	173	,,

Carbon in ash (sample taken 9th inst.)=2·77 per cent.

[1] Residue from bunkers, mostly dust.
[2] Day of stoppage for burning out.

TABLE No. 37

Details of Evaporative Test with two Lancashire Boilers each 30 feet long × 8 feet diameter, fired by a Kerpely Revolving Grate Gas Producer, Gasifying Waste Fuels

Date of test . . February 24th, 1922.
Duration of test . . 6 hours (8 a.m. to 2 p.m.)
Fuel gasified . . Waste fuel, Parrot and Belt pickings mixed (see Analyses below).

Time.	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 noon.	1 p.m.	2 p.m.
Weight of fuel charged, cwts.	..	24	13¼	24	12	12	18
Depth of fire .	2′ 10″	2′ 11″	2′ 6″	2′ 10″	2′ 6″	2′ 6″	2′ 10″
Steam pressure, inner, lbs.	65	65	60	60	40	40	40
,, ,, outer ,,	20	20	25	25	25	25	30
At producer main gauge,[1] lbs.	130	130	130	140	137	110	110
Blast pressure, inner	4½″	4½″	4″	4″	3¼″	3½″	4″
,, ,, outer	3″	3″	3½″	3½″	3″	3″	4″
Saturation temperature— Inner .	52° c.	53° c.	52° c.	52° c.	52° c.	52° c.	51° c.
Outer .	58° c.	55° c.	55° c.	55° c.	55° c.	55° c.	54° c.
Water in gauge (height) .	8¼″	..	..	..	..	..	8¼″
Boiler steam pressure, lbs.	130	134	132	138	140	142	107
CO in flue gases	..	..	..	..	..	..	14%
Draught	..	..	..	..	..	..	·25″
Lea integrator, unit 300 lbs.	042,857	042,888	942,919	042,952	042,984	043,008	043,045
Temperature of feed water[2]	50° c.	55° c.	53° c.	50° c.	52° c.	54° c.	54° c.

Total water evaporated = 56,400 lbs.
Total fuel gasified = 11,564 lbs.
Water evaporated per hour (average) = 9400 lbs.
Fuel gasified per hour = 1927 lbs.
Water evaporated per lb. of fuel gasified = 4·88 lbs.

Fuel Analyses

Description, ultimate analysis.	Parrot and Pickings. Dried at 105° C.	As received.	Proximate analysis as received.		Gas analysis.	
	Per cent.	Per cent.		Per cent.		Per cent.
Carbon	35·55	34·06	Fixed carbon (by difference)	24·50	CO	5·8
Hydrogen	3·50	3·35			O	·58
Nitrogen	0·65	0·62	Volatile matter	23·22	CO	23·21
Oxygen (by difference)	9·92	9·51	*Ash*	48·10	H	11·5
Sulphur	0·47	0·45	Moisture	4·18	CH	2·85
Ash	50·20	48·10			N	56·0
Moisture	..	4·18		100·00		100·0
	100·29	100·27				
Less correction for oxidation of pyrites	0·29	0·27	Sulphur included in fixed carbon, volatile matter and ash	= 0·45	..	..
	100·00	100·00				

Calorific value, B.T.U.'s per lb. = 6580.
Calories per kilo = 3655.

[1] Gauge inaccurate, see boiler pressure gauge figures.
[2] Feed water from producer jacket.

The Stein Chapman Gas Producer, with Mechanical Agitator.—The Stein Chapman producer which embodies an automatic feed, mechanical agitation and automatic ash extraction is illustrated in Fig. 102.

The coal hopper which will be seen in the illustration is kept filled with coal from a spout, which connects with an overhead bunker. Alternatively, if desired, the coal may be shovelled into the hopper from the ground level, the height being only 51 in. From the hopper the coal passes into a rotating drum. The drum is rotated intermittently by means of a rocking lever carrying a pawl, the lever being rocked by means of a connecting rod attachment to the face of a spur wheel, driven by a pinion, which is carried on the spindle of a 2 B.H.P. totally enclosed electric motor.

The interior of the drum is formed with three chambers, each having a capacity of from 40 to 60 lbs. of coal. As the drum rotates the chambers are filled in turn, and in turn discharge into the producer.

The drum acts as its own coal breaker, any lumps too large to enter the chambers being broken between the front edges of the chambers, and a sharp-toothed steel casting fixed in the hopper. A safety device in the form of a shearing pin is fitted in connection with the pawl.

The drum is slightly tapered outside so that it may be adjusted endwise in its housing, either to take up or increase clearance, for ease of rotation in case tar or dirt may accumulate around it. Spiral ribs are, however, provided on the outer surface of the drum, which tend to work out any soot, coal dust, or tar, which may get between the drum and its housing.

As the coal leaves the drum it slides down a chute and falls on to a centrally arranged steel bell, which scatters it evenly over the fire, adjustable deflectors being fitted to ensure uniform spreading.

The Chapman agitator is of what is known as the floating type, adapting itself to the height of the fuel bed. It rotates just beneath the average fuel level and does not break up the even and uniform bed of fuel below. Its operation is based upon the known condition of the fuel bed, which for a depth of from 6 in. to 18 in. is usually dense and difficult to blow through.

The agitator consists of a rake or horizontal arm carrying a series of stirring fingers, which project downward from the arm and also forward in the direction of movement. The agitator rotates on the top of the firebed, the fingers projecting downwards into it, harrowing or ploughing up the surface, which is levelled by the following action of the horizontal cross arm.

The depth at which the fingers operate in the fuel bed varies from 8 in. to 14 in., and is determined by the weight in the weight box. The most suitable depth depends upon the class of fuel being gasified.

The agitator is driven by a horizontal worm wheel, which in turn is driven by a worm on the same shaft as that on which is mounted the spur wheel carrying the coal drum connecting rod. The hub of the driving worm wheel is made with a pair of lugs projecting inwards, which engage a pair of screw-like spiral lugs formed on the driving head of the agitator.

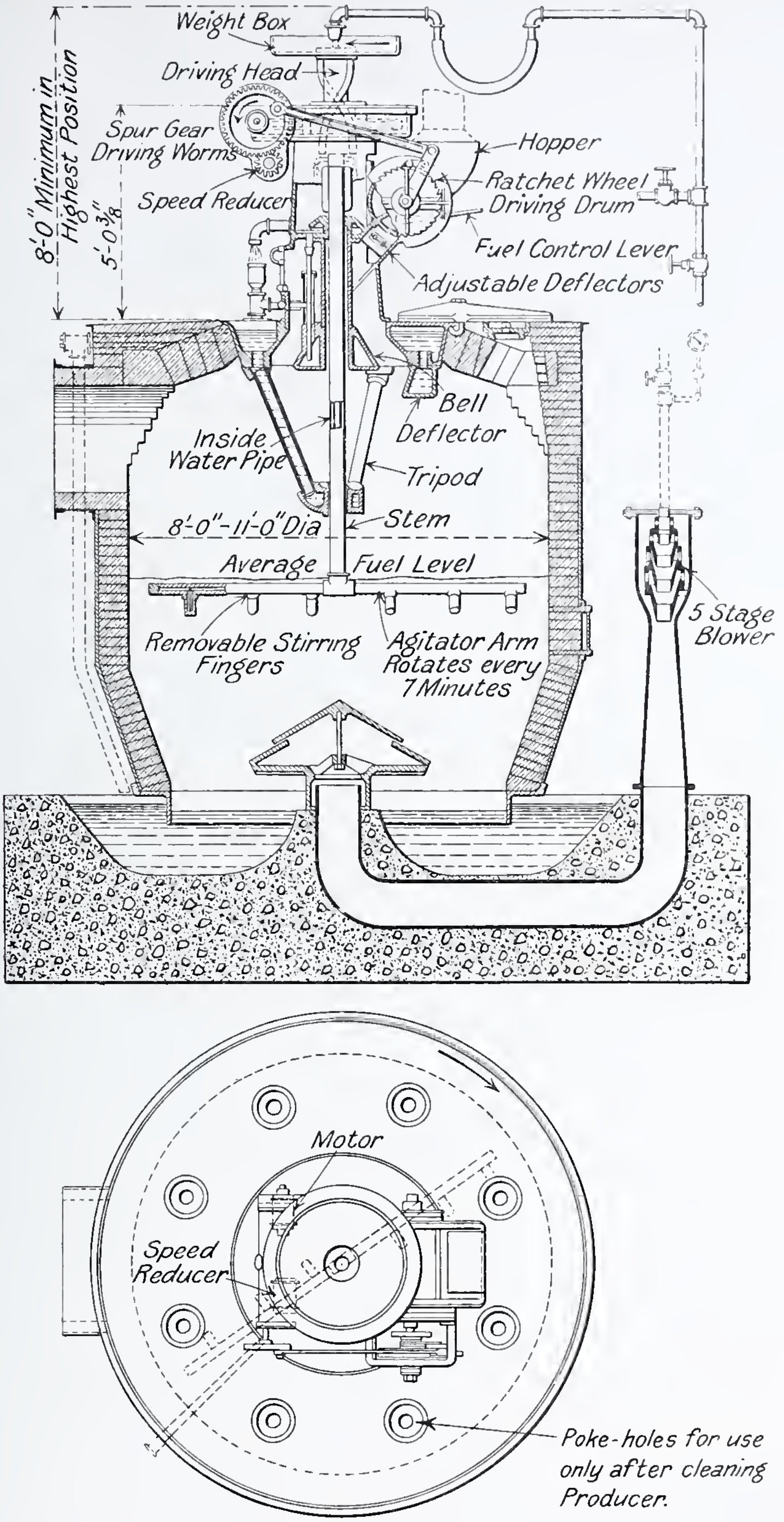


Fig. 102.—The Stein Chapman Producer with Mechanical Agitator.

In normal operation the worm wheel drives the agitator at about 7 revolutions per hour, so that every part of the fuel bed is covered 14 times per hour. If, however, the agitator strikes an obstruction or becomes covered too deeply with the fresh fuel, so that more power is required, the driving head automatically screws upward to a point at which the forces are again in balance. Similarly, if the top of the firebed falls too low the agitator follows it.

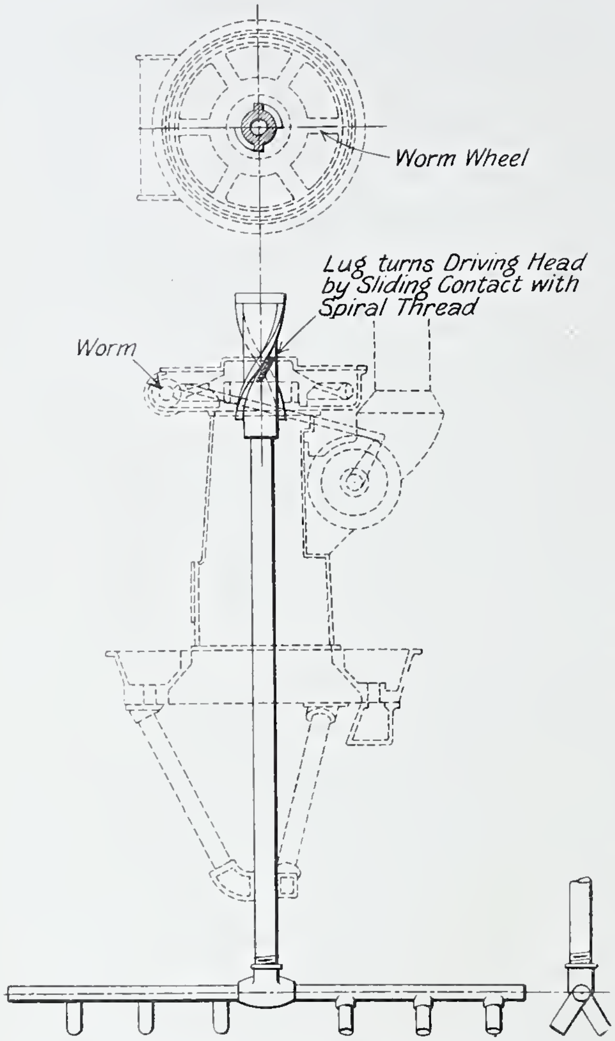


FIG. 103.—AGITATING ARM, STEM, AND DRIVING HEAD OF THE CHAPMAN FLOATING AGITATOR.

The main purpose of the floating provision is to maintain uniform treatment of the firebed independent of its level, but, as already observed, the arrangment also acts as a safety release in case the agitator strikes an obstruction.

Further provision against breakage is furnished by the cut out on the motor and the main fuses.

The stirring fingers are made of high carbon steel and can be easily replaced when worn out. The horizontal members are of tough metal, and have lasted for two years in continuous service, while there is no record of one having ever broken.

The agitating arm, stem and driving head of the Chapman floating agitator are shown in Fig. 103.

The Chapman " asher " or automatic ash extractor consists of an ashing beam, which is arranged diametrically across the ash pan. It is of cast steel, 2 in. thick, and 10 in. wide, and is curved backwards at the outer ends.

The ashing beam revolves continuously, and its speed may be adjusted from one revolution per hour to one revolution in ten hours. The backward curving ends of the beam result in more ashes being removed from the outer part of the firebed, where more are made. The beam is provided with agitating lugs or teeth, which project upwards and forward, through the ashes in the lower part of the producer. The teeth, which are removable in case of wear, finger down any large pieces of ash, and break up arches which may tend to form between the producer walls and the tuyere hood. They also agitate the ashes sufficiently to impart motion to all the lower part of the bed.

The ashing beam is supported at each end by a large gear ring which rotates continuously. The beam passes round the blast pipe under the tuyere head, but does not touch it, and has no bearing in the centre of the producer. Its bearings are all outside, where they are readily accessible for inspection and lubrication.

Attached to the rotating gear ring there are six scoops, the front edges of each set of three of which project downwards different distances into the ashes. The result of this arrangement is that each scoop as it revolves removes an equal quantity of the ashes, which have been forced out by the ashing beam. A fixed deflector is set diagonally over the ash pan, and as the scoops pass under it they are relieved of their load. The shape of the concrete ash pan is the same as in producers in which the ashes are shovelled out by hand.

The asher is driven by a motor and gearing entirely independent of the agitator drive, so that in the event of a breakdown of the ash removal apparatus, the ashes may be shovelled out by hand, without stopping the operation of the producer.

In a paper [1] read before the Manchester Section of the Society of Chemical Industry on February 2, 1923, by T. Roland, Wollaston, M.I.M.E., and A. L. Booth, A.I.C., after referring to the performance of ammonia recovery gas producers, the authors expressed the opinion that " there seemed to be three axioms :

" (1) Coke is always a good producer fuel. There is enough heat in the gas leaving the producer to coke, or at least semi-coke, the incoming fuel. If this coking is effected by direct contact between gas and fuel, the more volatile constituents of the latter will be taken up by and enrich the former. The final issuing gas will be cooled down considerably. Coke or semi-coke only will reach the producer.

" (2) High blast saturation in early recovery producers was adopted for physical rather than chemical reasons, that is to say, to reduce the temperature of the combustion zones, to avoid decomposition of the ammonia and to prevent the formation of clinker. Such moderation of temperature should be obtainable as well by useful radiation as by direct contact. The heat thus radiated is sufficient to generate all the steam necessary.

" (3) The water bottom type of producer is at once best and cheapest, mechanical and controllable discharge of ash is sound and economical. Hydraulic collection and discharge of large volumes of ash is a proved success, and highly economical."

Based upon the above conclusions the R.G. producer, the invention of Mr T. Roland, Wollaston, M.I.M.E., is perhaps the latest type of producer plant for the satisfactory handling of low grade fuels. A full size plant has been constructed having a capacity of 15 cwts. per hour, and has been thoroughly tested during the past twelve months, with some of the most difficult fuels available in this country, with eminently satisfactory results.

Upon reference to the accompanying illustration, Fig. 104, the reasons which will account for the remarkably successful results obtained will be apparent.

The design originated in the idea of producing gas under ammonia recovery

[1] *Journal of the Society of Chemical Industry*, May 11, 1923, vol. xl., No. 19, pp. 200 T, 203 T, " Recent Developments in Gas Producers," by T. Roland, Wollaston, M.I.M.E., and A. L. Booth, A.I.C.

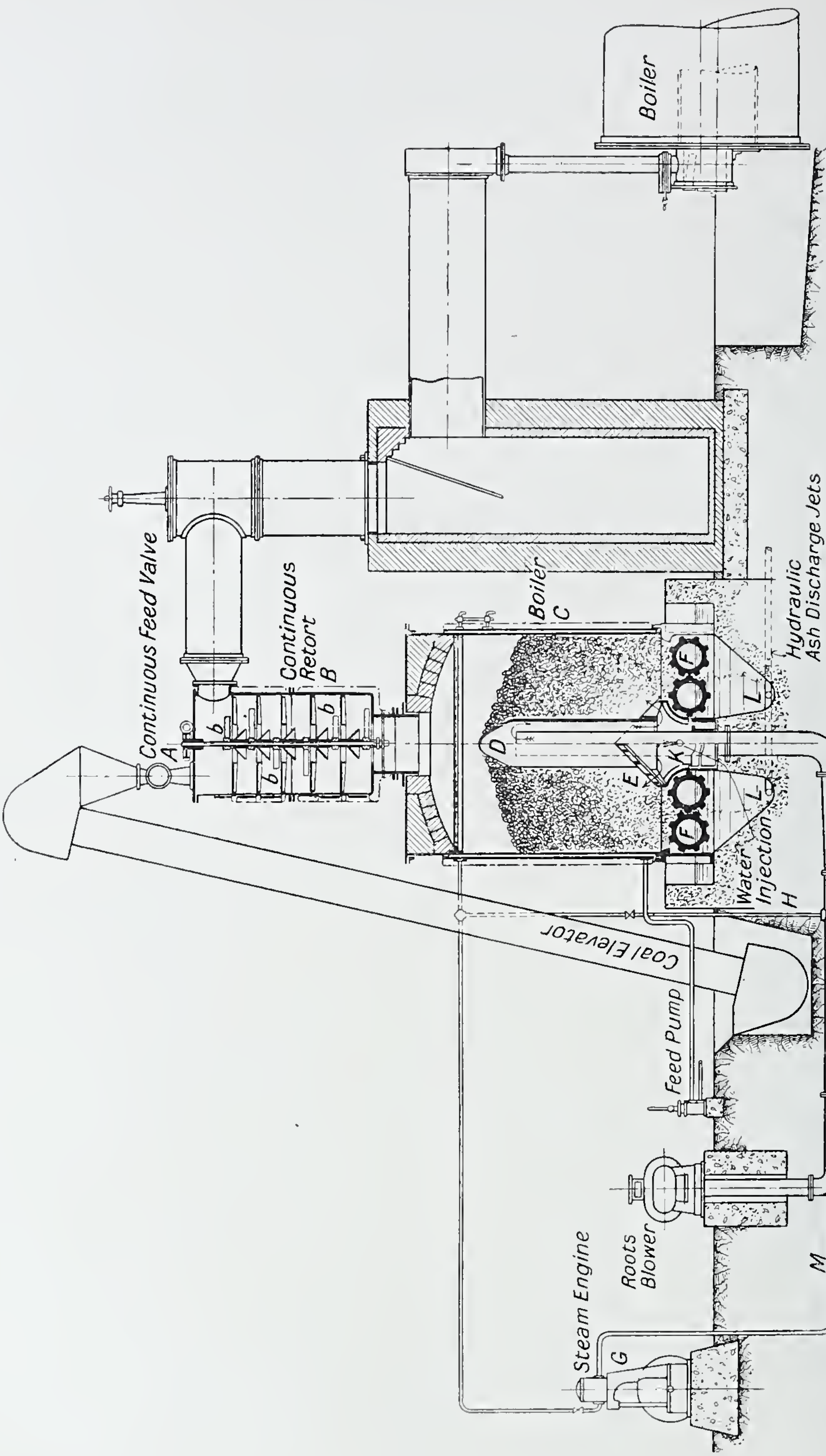


Fig. 104.—The R.G. Patent Producer.

conditions, as in the Mond system, but in working with much lower blast saturation, keeping the combustion zones and fuel bed generally at the necessary low temperature

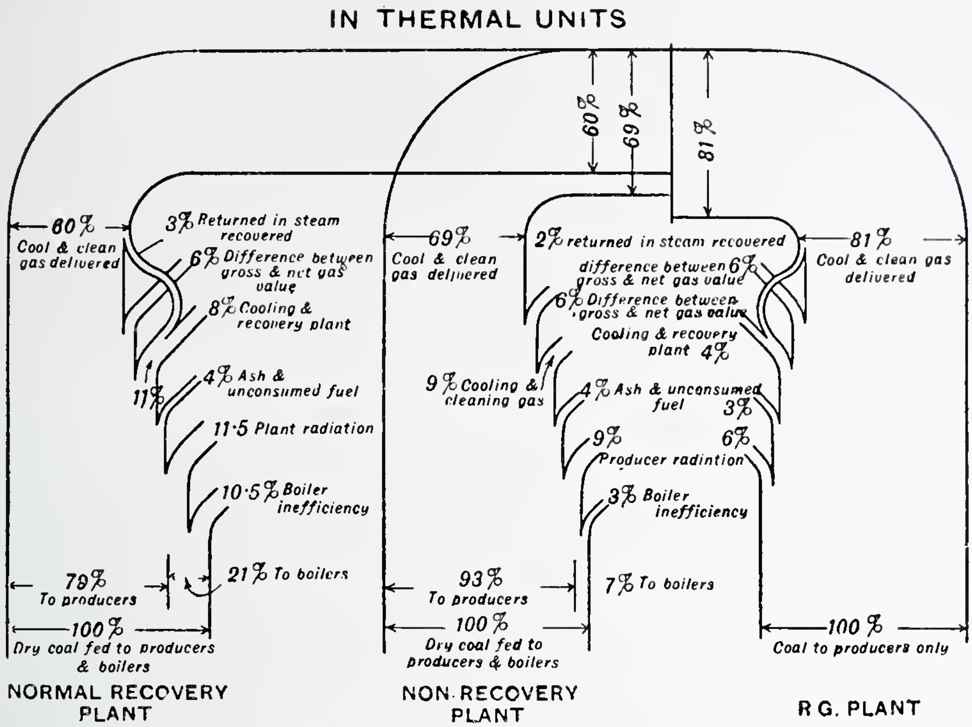


FIG. 105.

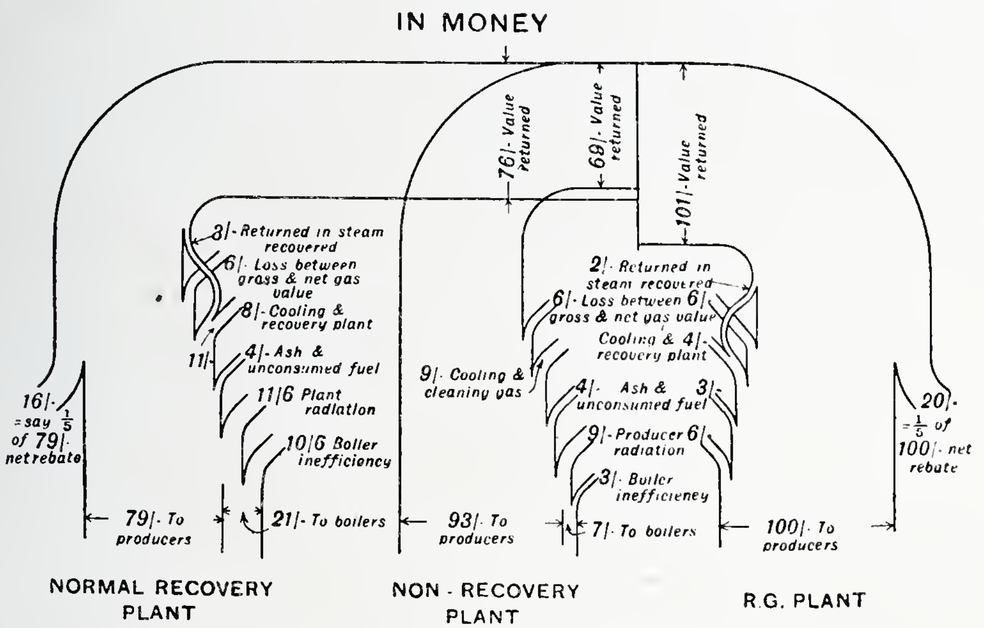


FIG. 106.—GRAPHS SHOWING RESULTS OBTAINED WITH R.G. PRODUCER.

by useful radiation of heat to the unlined boiler surrounding the producer, and to the central blast superheater. The producer thus generates all its own steam, with

an available surplus, and a gas more closely resembling "non-recovery" gas, *i.e.*, with high CO and moderate H. Well authenticated results are clearly shown in the accompanying graphs, Figs. 105 and 106.

The principal reason for the adaptability of this plant for low grade coal is in the provision of the superimposed retort through which the true producer gas finds exit. In this retort the descending coal is kept open, in motion and in contact with the outgoing gas, at a temperature averaging 500° C., which is sufficiently high to distil off the hydrocarbons (enriching the gas thereby), and to convert the fuel into a soft coke, ideal for gasification in the producer.

The nature of the fuel as regards ash content, swelling and caking properties, dust and moisture, have in practice no appreciable effect upon the ultimate coke dropped into the producer, and fuels which in coking swell to from five to six times their original bulk give no trouble. A further valuable feature is the efficiency of the retort as a dust catcher.

The fuel thus fed to the producer is not only free from caking qualities, but is also most suitable for the maintenance of even blast distribution, therefore permitting of very high rates of gasification per unit area. One of the most serious difficulties in the utilisation of low grade fuels in gas producers is that of clinkering. Such fuels usually contain a considerable proportion of ash which is fusible at a low temperature. In anticipation of this difficulty and for other reasons which apply more in the case of a battery of producers, the design of crusher roll grate shown was devised to crush and clear clinker.

During the whole of the trials it has been shown that this provision is unnecessary, and no clinker of appreciable size has been formed. This remarkable result is clearly due to the low temperatures attained throughout the fuel bed by reason of the rapid heat transference to the annular boiler and central blast superheater.

The outstanding advantages of this producer for the gasification of low grade fuels has been clearly demonstrated. Its performance when used in connection with by-product recovery is shown in the graphs, Figs. 105 and 106.

CHAPTER XI

STEAM BOILERS

Given normal conditions with a wide range of fuels to select from, the choice of the most suitable and efficient type of steam generator is not an easy matter, and necessitates the close consideration of various factors.

In the many excellent works on steam boilers, while every detail of existing types is exhaustively discussed, there is a noticeable reluctance to single out any one type of boiler as possessing outstanding advantages over all other types.

This attitude is not surprising, because under normal conditions there is no particular type of boiler which from every point of view is superior to all other types, and it is for this reason that the choice of the most efficient boiler demands careful consideration of all the factors involved.

In this chapter it is not proposed to discuss steam boilers in detail, but rather to direct attention to important features affecting the suitability of boilers of various types for the utilisation of low grade fuels. Hitherto in the selection of steam boilers this is an aspect which has not received that consideration which it merits. It will be submitted that if a steam boiler is considered primarily from the point of view of its suitability for utilising a wide range of low grade fuels, the choice of types is necessarily very restricted.

Among the more important factors which should receive consideration are (*a*) the grade or quality of fuel which it is desired to use, (*b*) the steam pressure required, (*c*) the desired evaporative capacity, (*d*) the nature of the demand for steam, *i.e.* whether even and unvarying, or fluctuating, and (*e*) the floor space and height available.

For convenience the various types of steam boilers available may be grouped as follows :

(*a*) Vertical type.
(*b*) Cornish ,,
(*c*) Lancashire ,,
(*d*) Water Tube ,,

Groups (*b*) and (*c*) will embody single flue economic, dry back, marine and multitubular boilers, as also double flue boilers of these types and Yorkshire boilers.

Vertical Boilers.—In any consideration of the comparative suitability of steam boilers of various types, having due regard to the conditions and facilities obtaining for the utilisation of low grade fuels, this type of boiler must to a large extent be regarded as useless.

Limited in grate area, restricted in combustion space, difficult to fire, and even more difficult to clinker, deficient in heating surface, inaccessible for inspection and cleaning, it may be said that the plain vertical boiler not only demands the use of good quality fuel for its operation, but even then rarely gives a thermal efficiency of more than 50 per cent.

With boilers of this type, owing to the very limited heating surface provided, it is a common experience to find the temperature of the exit gases as high as from 900° to 1000° Fahr.

The more efficient types of vertical boilers, such as the Cochran, Essex, and Spencer Hopwood, by reason of the ample heating surface provided, give a lower exit temperature in the gases, and accordingly an improved thermal efficiency, but for low grade and dirty fuels it cannot be said that they present good conditions in combustion space, limited grate area, and firing and clinkering facilities.

There are conditions which necessitate the use of boilers of the vertical type, as, for instance, very restricted ground space, or limited steam requirements. In all such cases there is no doubt whatever that from the point of view of cost of steam generation it would pay handsomely to instal boilers of the multitubular fire tube or water tube vertical type, *of ample size*, utilising coke breeze as fuel.

The characteristics of this fuel are such that with the restricted combustion space provided with all boilers of this type, it is specially suitable. The low volatile content, the high percentage of radiant heat transmitted, and the freedom from smoke trouble are points of much importance.

It is necessary to emphasise the necessity for providing a boiler of ample size, bearing in mind that the usual rated capacity of a boiler is based upon the use of the best quality coal and a good draught.

As a general rule it is desirable to instal a boiler of not less than 50 per cent. increased capacity if it is desired to burn coke breeze instead of good steam coal. Apart from any other consideration this is necessary in the case of vertical boilers in order to provide ample grate area.

The range of low grade fuels which can be utilised under the most favourable conditions is necessarily limited. As already observed the restricted combustion space demands the use of a low volatile fuel, while the facilities for clinkering are such that it is very important to limit the percentage of ash.

In the use of a dirty fuel not only is the removal of the incombustible very troublesome and wasteful, but owing to the small steam and water capacity of boilers of this type, the cleaning of the fire involves a very serious drop in the steam pressure.

Cornish Boilers.—About 120 years have passed since the Cornish boiler was introduced. All fire tube boilers, such as those of the Lancashire, Dry Back, or Economic, Yorkshire, and Lancashire and Cornish multitubular types, subsequently introduced, have been based upon or adapted from the standard Cornish design.

Cornish boilers vary in dimensions from 10 ft. long by 4 ft. diameter, to 24 ft. long by 6 ft. 6 in. or 7 ft. diameter, the normal evaporation ranging from 800 lbs. to 3500 lbs. of water per hour, and the working steam pressure from 80 lbs. to 200 lbs.

per sq. in. While Cornish boilers are occasionally constructed for the latter working pressure, the usual working pressures vary from 80 lbs. to 120 lbs. per sq. in.

As a reliable steam generator this type of boiler is very popular and is extensively used. In simplicity of design, sound construction and freedom from trouble it possesses obvious advantages, while in many small works the reserve of steam and water provided is very advantageous.

A standard Cornish boiler of the ordinary flat-ended type is illustrated in Fig 107. The dish-ended type of boiler, with an eccentric flue, is shown in Fig. 108. This arrangement of the flue or furnace tube is said to improve the circulation,

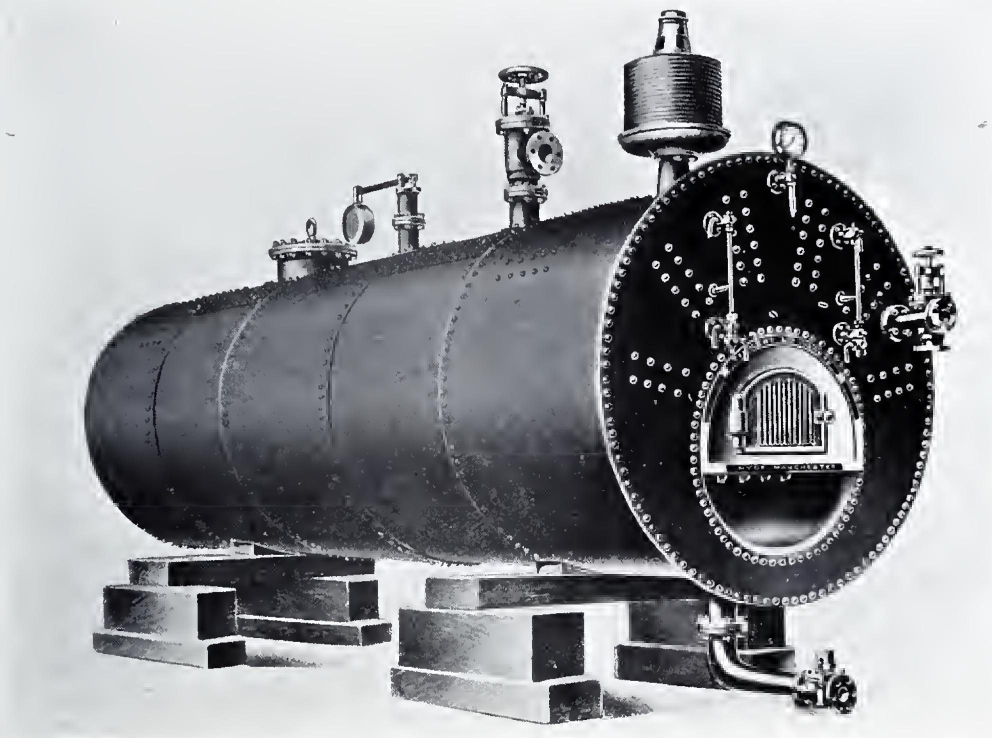


Fig. 107.—Cornish Boiler, Flat End Type.

to what extent this claim is realised in practice is open to question, but it certainly does to some extent facilitate internal examination and cleaning.

For an evaporation of up to 2000 lbs. of water per hour it is doubtful whether the Cornish boiler offers any outstanding advantage in efficiency over the best types of vertical boilers. The ground space occupied is considerably more, while the capital expenditure involved for a Cornish boiler, its brickwork setting, and chimney will be much higher.

Regarded solely from the point of view of low grade fuel utilisation, the Cornish boiler is more satisfactory than the vertical boiler, providing as it does better facilities for firing and clinkering.

For an evaporation of from 2000 to 3000 lbs. of water per hour a Cornish boiler of ample size may be arranged to utilise a wide range of low grade fuels, and if

provided with a hot feed water supply, will usually show a higher thermal efficiency than a vertical boiler of equivalent heating surface.

Lancashire Boilers.—The Lancashire boiler was first introduced in 1841, and with the type just discussed has been deservedly popular. It is estimated at the present time that from 80 to 85 per cent. at least of the steam boilers in use in Great Britain are either of these types, or of types based upon the same.

Lancashire boilers vary from 6 ft. in diameter and a length of 18 ft., to 9 ft. in diameter and a length of 30 ft., the working pressures ranging from 80 lbs. to 200 lbs. per sq. in.

The smaller Lancashire boilers, *i.e.* those of 6 ft. diameter, are now but rarely installed, and may be regarded as obsolete practice. Such boilers are provided with furnace or flue tubes of about 25 ln. internal diameter, presenting very cramped and limited combustion space, whiie also being very inaccessible.

The heating surface of a Lancashire boiler 20 ft. long by 6 ft. diameter is

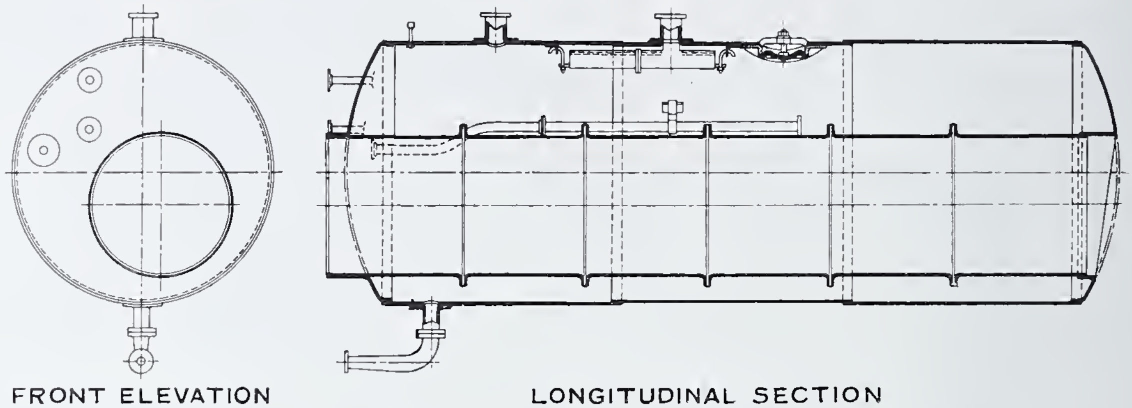


Fig. 108.—Cornish Boiler, Dish End Type with Eccentric Flue.

475 sq. ft., and its rated evaporation 3300 lbs. of water per hour. A Cornish boiler 22 ft. long by 6 ft. 6 in. diameter has 455 sq. ft. of heating surface, and a rated evaporation of 3185 lbs. of water per hour.

In practice it is found that the larger combustion space is of great advantage, permitting the use of such low grade and dirty fuels as could not be utilised with the Lancashire boiler.

The much larger fire door facilitates both firing and clinkering, while the increased area provided above the grate presents much better conditions for combustion.

Generally speaking, it is not good practice to instal a Lancashire boiler having a diameter of less than 6 ft. 6 in. with furnace tubes of 2 ft. 6 in. internal diameter. Having in mind that the grate level is usually arranged at the centre line of the flue, with a fire 8 in. in thickness, the available combustion space of only 7 in. to the crown of the furnace is exceedingly limited, and the conditions presented for the efficient burning of any fuel, other than those of low volatile content, are most unsatisfactory.

Although the great bulk of Lancashire boilers in use are of the flat-ended type,

as illustrated in Fig. 109, dish-ended boilers are now being much advocated, and a considerable number are in use. While this type of boiler is cheaper to manufacture than the flat-ended type, extended experience only will show whether the dish-ended design embodies any outstanding advantage over the earlier design.

For long life, with low maintenance cost and comparative freedom from trouble, the Lancashire boiler of the flat-ended type enjoys a high reputation. Boilers of the dish-ended type have not yet been in use for a sufficient length of time to

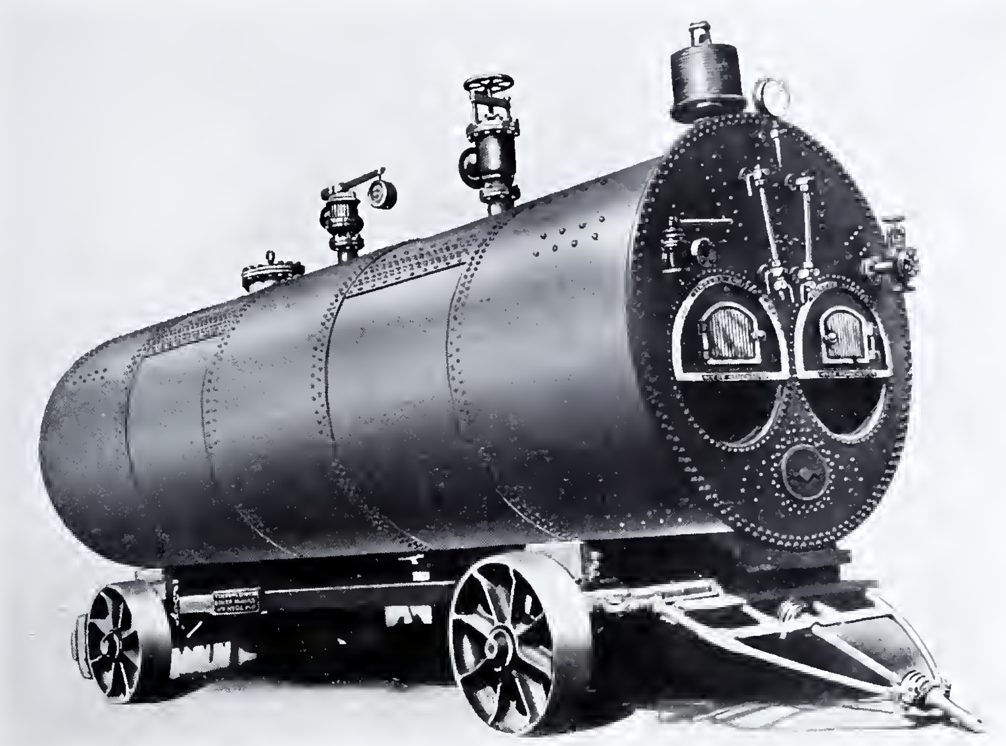


Fig. 109.—Lancashire Boiler, Flat End Type.

determine whether they possess any appreciable advantage from the point of view of durability.

On the contrary, Lancashire boilers of the flat-end type have in many cases been in continuous use for from twenty to thirty years, with a comparative immunity from trouble and expense, even under conditions which cannot be regarded as entirely favourable. In common with the Cornish boiler the Lancashire type provides a large steam and water reserve. In many industries where the demand for steam fluctuates, this is a feature of considerable importance, enabling sudden and heavy demands for steam to be met without a serious drop in the pressure.

While the provision of good feed water is desirable with steam boilers of every type, generally speaking it is less important with Lancashire and Cornish boilers than is the case with other types, and particularly water tube boilers, which will be discussed later.

Yorkshire Boilers.—The Yorkshire boiler, illustrated in Fig. 110, was introduced

in 1907, and differs from the Lancashire type mainly in its maximum length, which is limited to 24 ft., in the design and arrangement of the furnace or flue tubes, and in the provision of a standardised grate area, which is always in constant ratio with the exit area of the furnace flues.

As will be observed upon reference to Fig. 110, the two furnace flues expand from front to rear, increasing the area of the gas outlet to the extent of 30 per cent. This arrangement of the furnace flues provides for the highest temperature, the smallest heating surface, and the greatest weight of water at the front end where the transmission of heat is most rapid, and the largest heating surface, with the

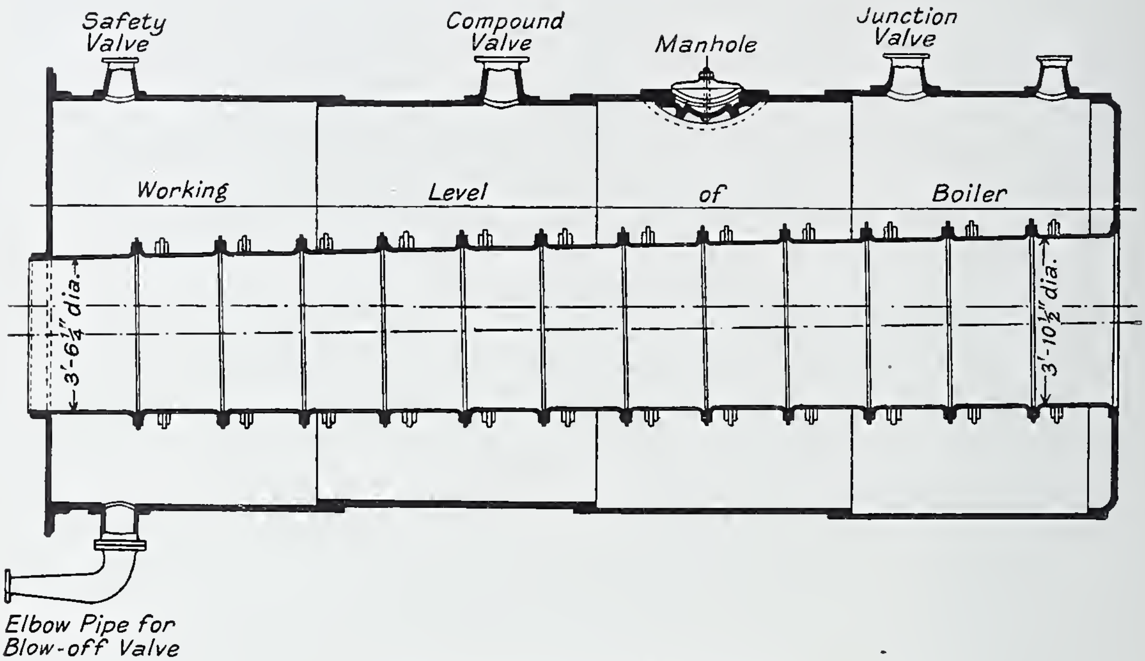


FIG. 110.—THE YORKSHIRE BOILER.

smallest weight of water, at the rear end of the boiler where the temperature of the gases is lowest.

The ratio of grate area to the aggregate outlet area of the furnace flues is 1·8 to 1 in all sizes of boilers. The Yorkshire boiler is made in a number of sizes from 6 ft. diameter and 17 ft. long to 9 ft. 4 in. diameter and 24 ft. in length. The rated evaporation of the smallest standard boiler is 2898 lbs. per hour, and that of the largest boiler 11,000 lbs. per hour.

Economic or Dry Back Boiler.—This type of boiler differs from the Lancashire, Cornish and Yorkshire types in the provision of increased heating surface in the form of fire tubes extending throughout the water space of the boiler above and at the sides of the furnace tubes. The gases leaving the furnace tubes at the rear return to the front of the boiler through the fire tubes into a smoke box arranged above the furnace flues.

If, as is the common practice, the boiler is set in brickwork the gases leaving the smoke box then traverse the side flues to the main flue and chimney.

In some cases, however, small boilers of this type are not set in brickwork, the boiler being set upon cradles, in which case the gases pass direct from the smoke box to a chimney set immediately above.

Boilers of this type are usually limited to a length of 14 ft. and a maximum diameter of about 11 ft. Compared with a Lancashire boiler 30 ft. long by 9 ft. having 1120 sq. ft. of heating surface, an Economic boiler 14 ft. long by 9 ft. diameter has 1640 sq. ft. of heating surface, and assuming in each case an equal coal con-

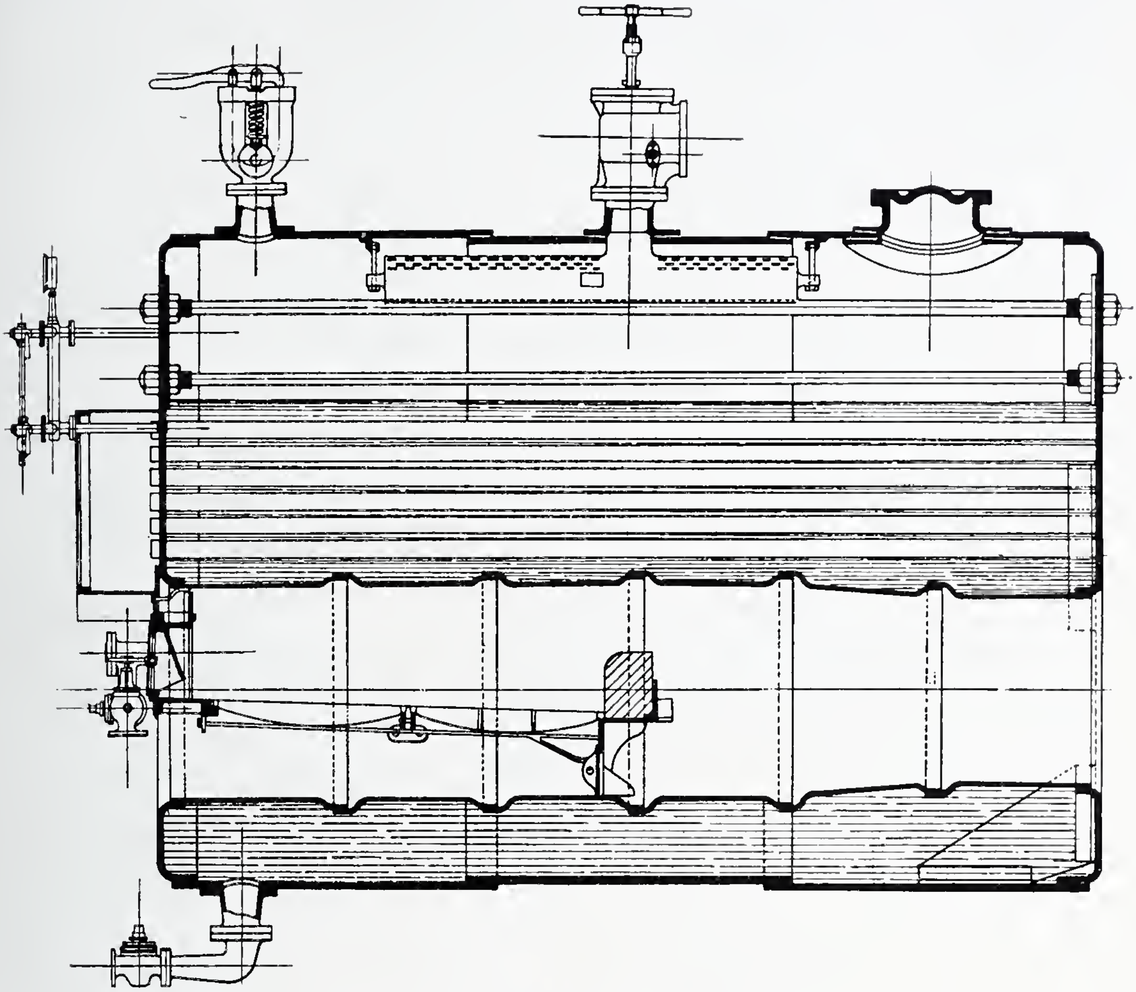


Fig. 111.—The Paxman Economic Boiler.

sumption per hour, the exit temperature of the gases from an Economic boiler will obviously be much lower, with a corresponding gain in efficiency. It is for this reason that the use of economisers with boilers of this type is not generally advocated.

Where ground space is an important factor the Economic boiler is advantageous by reason of its reduced length, less expensive setting, and the very ample and compact heating surface provided. For a shell boiler it is quick steaming, but in the provision of steam and water space it is not so satisfactory as the Lancashire type, while it is also more difficult to clean and more costly to maintain.

The Paxman "Economic" boiler is illustrated in Fig. 111.

Externally Fired Multitubular Boiler.—This type of boiler, while very extensively used in the United States and in some other countries, has not been adopted to any extent in this country, where it has never been regarded as a serious competitor of established types, such as Cornish and Lancashire boilers.

Locomotive Type Boiler.—Another type of boiler which is largely used in laundries and small works is the Locomotive type. In working efficiency with a good quality of fuel it has a very satisfactory record, but it is difficult to keep clean, and generally cannot be compared with Lancashire and Cornish boilers from the point of view of accessibility and low maintenance cost.

Water Tube Boilers.—Water tube boilers were first used about half a century since, but it is only within the past twenty years that they have been extensively adopted.

The advantages of the water tube boiler may be briefly stated as follows :—

1. High steam pressures can be used with safety.
2. The saving in ground space occupied for a given steam output is considerable.
3. Much greater heating surface and evaporative capacity can be provided in a single boiler unit.
4. Rapidity in steam generation, and greater flexibility.
5. Larger grate area, better combustion conditions, more easily adaptable to the use of a wide range of fuels, and various methods of firing.

Against the advantages must be set the disadvantages of boilers of this type, which are :—

1. Small water capacity.
2. The necessity for using pure feed water.
3. The need for greater attention than is devoted to boilers of other types.

The water tube boilers now on the market may be divided into two distinct classes or types, viz., the header type, and the direct tube to drum type. The former type comprise the Babcock & Wilcox, Spearing and Niclausse boilers, while among the latter type are the Stirling, Woodeson, Nesdrum, and Thompson boilers. Each of these types embody distinctive features in design, and may be taken as typical of the best British practice in water tube boiler design.

The present tendency is to provide much higher steam pressures, the practicable limit of pressure with shell boilers such as the Lancashire type has long since been exceeded, and for pressures above 180 to 200 lbs. the use of a water tube boiler is essential. A number of boilers of this type are now in use at a working pressure of 350 lbs. per sq. in., higher pressures are occasionally asked for, while a pressure of 250 lbs. is now common practice.

With increasing steam pressures there has also been a constant increase in the evaporative capacity of boilers. Only a very few years since a boiler having an evaporative capacity of 20,000 lbs. per hour was regarded as a very large unit.

Boilers having a capacity of from 50,000 to 70,000 lbs. of water per hour are now in constant demand, and a considerable number have been installed. At the

Barton Generating Station, of Manchester Corporation, boilers of each having a capacity of 100,000 lbs. per hour have been installed.

Among the largest boiler units which have been put into service in Europe are the Stirling boilers at Gennevilliers Generating Station, Paris.

Each boiler unit has the following heating surface :—

	Square feet of heating surface.
Boiler	22,600
Superheater	10,764
Economiser	12,915
Air heater	19,350

The working pressure is 355 lbs. per sq. in., and the final steam temperature 752 degrees F. Each boiler is capable of evaporating 175,000 lbs. of water per hour, an equivalent evaporation to, say, 25 to 30 ft. by 8 ft. Lancashire boilers.

In the United States single boiler units are in use, each giving an evaporation of 225,000 lbs. of water per hour, while at present boilers are being made having an evaporative capacity of up to 400,000 lbs. of water per hour.

For rapidity in steam generation the water tube boiler is unique, by reason of the more rapid water circulation, the increased freedom for expansion and contraction—due to temperature changes—rendered possible by the construction of the boiler, and the comparatively small dead weight of water contained in the boiler.

The larger grate area, and the considerable increase in the combustion space, which may be provided by setting the boiler sufficiently high, are factors of great importance, not only in enabling a very wide range of fuels to be utilised, but in ensuring the most efficient combustion conditions.

While the small water capacity of this type of boiler presents conditions suitable for rapid steam generation, the small reserve of water and steam renders the use of a boiler of this type undesirable in some industries, owing to the peculiar nature of the load and the great fluctuations in the demand for steam.

There is a further point : with but a limited water capacity any interruption in the boiler feed involves a serious reduction in the water level, and a complete stoppage of the feed must quickly result in the emptying of the boiler.

The use of a pure feed water is essential with water tube boilers, and any neglect in this direction not only affects the efficiency of the boiler, but to a very large extent determines the cost of its upkeep and maintenance.

The need for skilled and careful attention is of much more importance than is the case with a Lancashire boiler, and it is useless to ignore this factor.

General Conclusions.—Reference has already been made to the limitations of the vertical type of boiler for the utilisation of low grade fuels. To a greater or lesser extent these limitations apply to every other type of internally fired boiler.

It must be admitted that a considerable number of Lancashire and Cornish boilers are being fired with a variety of low grade fuels, but there is no doubt that

the evaporative duty and efficiency obtained are low, while in connection with the larger installations the labour involved is too often excessive.

To a large extent the results obtained in the burning of low grade fuels in internally fired boilers have been disappointing to steam users, and in many hundreds of cases the use of low grade fuel has been abandoned in spite of the apparent advantage of a relatively low price per ton.

Hitherto the experience in the use of low grade fuels for steam generation has been mainly confined to internally fired boilers, which are not suitable for firing with such fuels, *if the full rated evaporative output is desired.*

In the average case the steam user requires the full rated evaporative duty, or an output approximating very closely thereto, and experience has conclusively shown that whether boilers are machine fired or hand fired the requirements cannot be met without continuous forcing, and a certain sacrifice in thermal efficiency, to say nothing of excessive wear and tear and high labour cost.

In such circumstances it will be apparent that an initial advantage of several shillings per ton in the *cost* of fuel per ton may in the final result prove to be of no commercial benefit whatever.

To take a typical case. With one Lancashire boiler, 30 ft. long × 8 ft. diameter, Welsh steam coal was being burned costing 40s. per ton delivered, the ash content being 7 per cent. The rate of combustion averaged 23 lbs. per square foot of grate per hour (grate area 38 sq. ft.), the evaporation being at the rate of 7500 lbs. per hour.

Instead of Welsh steam coal, it was decided to burn a fine Leicestershire slack costing 28s. per ton delivered, with an average ash content of 21 per cent., and a moisture content averaging 6 per cent. Having in mind that grates 6 ft. long were previously used, it was undesirable to increase the grate area, with the result that the evaporation was reduced to 5700 lbs. per hour, when burning at the rate of 30 lbs. per sq. ft. of grate per hour.

Even had it been possible to burn upwards of 39 lbs. of fuel per square foot of grate per hour continuously, and thus obtain the desired evaporative output, the comparative financial results would not have encouraged the continued use of the low grade and cheaper fuel, inasmuch as the extra fuel cost alone would have been at least 2s. 10d. per hour.

It is scarcely necessary to observe that burning fuel at the rate of upwards of 39 lbs. per square foot of grate per hour involves inefficient operation, while to expect a fireman to handle 1500 lbs. of fuel per hour, as also 360 lbs. of incombustible, instead of 874 lbs. of coal and 61 lbs. of ash, and to be enthusiastic, is, to say the least of it, to expect rather too much from human nature.

This typical case clearly illustrates why there has been and still is a disposition to avoid the use of low grade fuels; it further serves to show not that an internally fired boiler is unsuitable for burning a low grade fuel, but that impossible results are expected by the steam user, and promised by the vendor of firing equipment.

In the case discussed, had the evaporative output required been 4000 lbs. per hour,—in other words, had the boiler been amply large for the evaporative duty

demanded,—it would have been possible to have obtained the required evaporation with a reduced grate area, a higher efficiency, and a consumption of 5 cwts. of fine slack per hour at a cost of 7s., as compared with 4 cwts. of Welsh coal at a cost of 8s.

Low grade fuel has almost invariably been regarded as useless, because unreasonable results have been anticipated under impossible conditions.

It cannot be too strongly emphasised that if it is desired to use low grade fuel with an internally fired boiler, it is essential that the boiler should be amply large, and the evaporative duty demanded should be from 30 to 50 per cent. less than the rated capacity.

Internally fired boilers of the fire tube type—*i.e.* dry back or locomotive type boilers, as also externally fired boilers of the multitubular type—are less satisfactory than Lancashire and Cornish boilers for firing with low grade fuels, owing to the rapid and constant accumulation of dust and fine fuel in the fire or smoke tubes, with an increasing loss of heating surface; and as the result of reduced area, a certainty of back draught.

Yorkshire boilers offer no practical advantage over boilers of the Lancashire type for the utilisation of low grade fuels, inasmuch as the furnace and combustion conditions are practically identical.

There is but little doubt that for all internally fired boilers the most suitable fuels from the point of view of thermal efficiency are those having a volatile content of from 5 to 20 per cent. Owing to their low volatile content both coke and coke breeze might be advantageously used for internally fired boilers to a far greater extent.

High volatile fuels are wasted to an extent which is not generally realised when burned under the unfavourable conditions presented in the furnace of an internally fired boiler, owing to the difficulty of ensuring complete ignition and utilisation of the large volume of volatile gases as distilled.

Given a suitable boiler, its efficiency in the use of low grade fuels will depend to a very large extent upon the efficiency of the firing equipment provided, as also its operation and control. From every standpoint the water tube boiler would appear to be the most suitable boiler for the utilisation of low grade fuels. It possesses an adaptability such as does not obtain with any other type of steam generator.

For instance, the design lends itself to oil or gaseous firing, or for the efficient utilisation of wood waste, sawdust, timber or bagasse in specially designed furnaces. If provided with mechanical stokers with adequate grate area, coke breeze may be burned, or a wide range of low grade or high moisture fuels, while obtaining the full rated evaporative output from the boiler, and, if so desired, a reasonable overload.

Taking the other extreme in fuel. A water tube boiler set sufficiently high, and providing adequate combustion space, will give a higher thermal efficiency with a rich high volatile coal than can be obtained with any other type of boiler.

For firing with pulverised fuel, whether high in ash or low in volatile content,

or *vice versa*, there is no other type of boiler which can be used with an equal degree of efficiency or satisfaction. Having in mind that pulverised fuel firing is certain to be very widely adopted within the next few years, and that the use of fuel in this form will give an immense impetus to the utilisation of very small fuels, which are at present to a large extent wasted, this is a point of considerable importance.

For the efficient utilisation of waste heat, whether in the form of blast furnace gases having a calorific value of 100 B.T.U.'s per cubic foot, coke oven gas having a calorific value of 500 B.T.U.'s, or gases from a refuse destructor, this type of boiler is generally conceded to be superior to all other types.

This adaptability of the water tube boiler is possible because the boiler is externally fired, and also because it may be so set as to provide a sufficiency of cubic area between the grate level, or the firing floor, and the tubes, to meet the requirements of any fuel or any system of firing.

Similarly in regard to grate area, while from 6 ft. to 7 ft. would of necessity be the limit in length for hand firing with any type of boiler, a chain grate or travelling grate mechanical stoker may be installed, providing a furnace length of from 14 to 16 ft., thus making it possible by considerably increasing the grate area to mechanically fire and utilise low grade fuels such as could not otherwise be utilised, as also to obtain therefrom an evaporative output such as would be quite impossible under hand fired conditions.

A further important point in the burning of solid fuels with boilers of every type is the disposal of the ash or incombustible. When low grade fuels are used the percentage and total weight of incombustible residual which has to be handled often presents a very serious problem.

With internally fired boilers fired by hand, the cleaning of the fires and the removal of the ash is laborious and expensive. If the boilers are machine fired, the incombustible is by the reciprocating motion of the firebars automatically carried over the rear of the grate to the ash chamber. As the storage capacity of this chamber is necessarily very limited, if the fuel is very dirty this deposit has frequently to be raked through the ashpits for removal.

With machine fired water tube boilers the removal of incombustible is much simplified, and may be both continuous and automatic. By providing ash hoppers, and an underground ash tunnel, the incombustible passing over the dumping bars at the rear of the grate enters the ash hopper, which in turn delivers it either on to or into an ash conveyor, or alternatively into trucks ready for removal.

Considered from every point of view it must be conceded that the externally fired boiler embodies facilities for the utilisation of a very wide range of fuels, both high grade and low grade, and solid and gaseous. It may be regarded as unfortunate that no other type of boiler offers equivalent advantages, but, as will have been observed, the determining factors are, and must be, grate surface and combustion area.

Important as these factors are under all conditions and with every class of fuel, in the efficient utilisation of low grade fuels they are of paramount importance, and as such cannot be disregarded.

Internally fired boilers provide both a very restricted combustion space which cannot be increased, and for all practical purposes a fixed grate area ; the width is constant, and the length can only be varied within very narrow limits.

At present there is no sign that internally fired boilers will be rapidly superseded by water tube boilers for general industrial use, but there are distinct signs that at collieries, and at the larger works adjacent to coal fields, machine fired water tube boilers will gradually displace boilers of the Lancashire type, enabling low grade and cheaper fuels to be efficiently utilised in increasing quantities, at or near to the point of production, with a considerable reduction in both fuel and labour cost

CHAPTER XII

FURNACES AND FIRING

Given the most suitable type of steam generator, the efficient utilisation of low grade or waste fuels will to a very large extent be determined by the furnace equipment provided, as also its operation and control. The term furnace equipment is used in its broadest application, and is intended to cover every system or method of burning solid fuel on grates.

When discussing the utilisation of various fuels, and also the comparative suitability and efficiency of steam boilers of various types, in previous chapters, it has been necessary to refer to methods of firing, inasmuch as the practical value of any fuel is determined by the means employed for its use.

The problems presented in efficient firing are deemed to be of sufficient importance to warrant discussion in a separate chapter. For this reason it was decided to devote this chapter to the consideration of furnaces and firing.

Machine Firing.—Rather more than a century has passed since the first mechanical stokers, then termed " Fire Regulators," were put into successful operation in this country, both in London and Birmingham.

Even the strongest advocate of machine firing will scarcely contend that with a history of one hundred years behind it, the mechanical stoker of to-day, more particularly as applied to internally fired boilers, is a perfect apparatus, or that it adequately meets all conditions and requirements.

It is true that mainly with a view to preventing or minimising the emission of black smoke, improving firing conditions, and also saving labour, mechanical stokers have been very extensively adopted, but it is equally true that many hundreds have been dismantled in favour of hand firing.

Theoretically machine firing should show a distinct improvement over hand firing in every respect ; actually this has not been the case in a very large number of installations. Generally speaking, in any boiler house where more than two boilers are in use together, there is, or should be, a definite saving in labour cost, but against this has to be set the disadvantages of machine firing, which may be briefly summarised as follows :—

(1) That some mechanical stokers both of the coking and sprinkling types do not cover the grate with fuel *and keep it covered.*

(2) That with most makes of mechanical stokers it is imperative to select suitable fuel, they will not efficiently burn a wide range of fuels, and particularly low grade fuels, without a considerable sacrifice in evaporative output.

(3) That as a general rule the cost of upkeep and maintenance is much too high.

(4) That in the event of a breakdown it is usually impossible to resort to hand firing, with any degree of satisfaction.

These are points of importance which it is useless to belittle; they are, moreover, points which in the evolution and development of the mechanical stoker have not even yet received that close attention which they not only merit, but demand. To discuss the above points seriatim.

(1) Failure to cover the grate evenly with fuel, and to keep it covered, involves the passage of excess air through the grate, and is a direct and grievous cause of inefficiency and loss.

It must be conceded that with coking fuels there is a tendency for the fuel to "mass" at the front, and move forward more or less in bulk. The nature of the fuel may be blamed for this disadvantage, but at the same time it may be assumed that the coking stoker is, or should be, designed for the use of coking fuels, and that such fuels should adequately cover the grate.

The defect in question is not peculiar to coking stokers or coking fuels. With some mechanical stokers of the sprinkler type the distribution of the fuel is such as to leave bare or thinly covered portions of the grate immediately inside the fire doors on both sides; further, there is a tendency not to adequately cover the grate at the sides throughout its length.

There is no doubt that a *skilled* fireman can cover a grate of reasonable length and keep it covered more evenly and thoroughly than is possible with machine firing. It is true that in this respect some mechanical stokers are more satisfactory than others, but in the opinion of the author even the most satisfactory feeding mechanism falls short of the results which can be obtained in the intelligent "placing" of the fuel by a skilful fireman.

Automatic feeding mechanism requires intelligent adjustment or regulation in order to secure satisfactory results, and unfortunately machine fired apparatus very frequently does not receive that attention which it demands.

(2) There has been much disappointment among those who have adopted mechanical stokers owing to the limited range of fuels which can be efficiently used. It has been found that there is not the same elasticity as with hand firing; in short, instead of the mechanical stoker being suitable for efficiently burning a reasonably wide range of fuels, too often experience has shown that the fuel must be selected to suit the firing equipment.

In the best interests of the steam user it is not desirable that he should be in any way tied to the use of a particular fuel, obviously he is placed in a much more satisfactory position if able to change the source of supply without delay or inconvenience.

Low grade fuels with a high ash content present difficulties when burned with mechanical stokers in internally fired boilers. While all moving parts are not exposed to such trying conditions as when surrounded with incandescent walls, as in the case of water tube boilers, the combustion space is restricted, and under

such conditions given a dirty fuel of low calorific value the rate of combustion must of necessity be high in order to obtain the required evaporative output.

The effect of this is to reduce the thermal efficiency, and to carry over into the flues an excessive quantity of ash and fine fuel, both partially consumed and to a large extent unaffected by the fire. The necessarily limited space behind the grate for the reception of clinker and ash also presents a difficulty and must be frequently cleaned, which involves raking the contents of this chamber and the ashpit to the front for removal.

The author is of opinion that the best all-round results with mechanical stokers applied to boilers of the internally fired type can be obtained with fuels having a volatile content of from 10 to 20 per cent. and an ash content not exceeding 10 per cent. While this narrows the range of fuels which can be thus utilised, its general recognition would tend to bring about a marked and widespread improvement in the efficiency of operation.

It would obviously be foolish to blame mechanical stokers for the unfavourable combustion conditions under which they are required to operate. That these conditions with internally fired boilers are unfavourable is not a matter of opinion, but a matter of fact. This being so, in their own interests, as also the interests of the steam user, it would surely be preferable for the makers to recommend a range of suitable fuels, rather than claim to burn with efficiency any fuel of suitable size from a very low grade and dirty slack, to rich high volatile washed nuts.

(3) This may best be discussed in conjunction with No. 4.

There can be no question that the cost of upkeep and maintenance has been far too heavy. To some extent this has been due to the fact that careful periodical inspection has unfortunately not been the common practice. Repairs which at an early stage would not be troublesome or expensive have been and are neglected until they become compulsory and costly.

Given careful and systematic inspection and attention, with replacement at the proper time, there is no doubt that the cost of maintenance may be considerably reduced. It is not the actual cost of replace parts alone which has given cause for disappointment and dissatisfaction, but the cost of labour for week-end work, or the contingent cost of a stoppage or partial stoppage, due to a breakdown, and also the fact that reasonably satisfactory hand firing as a temporary expedient has been found to be impossible.

In the desire to encourage the adoption of machine firing there has been a disposition upon the part of mechanical stoker makers to disregard or belittle the importance of skilled attention. Despite all that may be said to the contrary by those who are interested, machine firing demands either skilled attention or alternatively close, regular, and systematic supervision, in order to obtain the best results, and the minimum cost of maintenance. To ignore this is to court trouble, expense, unreliability, and inefficiency.

It is still claimed that it is worth while to instal mechanical stokers in connection with a single Lancashire boiler, but unless under specially favourable and unusual conditions it is difficult to realise wherein the advantage lies.

In actual labour cost little or nothing can be saved. A capital expenditure of from £150 to £200 or more is involved, with possibly an annual maintenance cost of from 15 to 20 per cent. of the capital cost.

With three or more boilers in use there should be a clear advantage in labour cost, particularly if coal and ash handling plant are installed. When such an installation is operated for three shifts daily, the saving in labour cost should be considerable.

Apart from this aspect, there is no doubt that machine firing and mechanical coal and ash handling, materially improves the boiler house conditions. This is a factor of some importance and one which will have to be faced. The working conditions in many boiler houses are deplorable, and cannot be calculated to encourage the best interest or effort.

Although it has been claimed that machine firing is well adapted for all conditions of load, and that a fluctuating load does not present any difficulty, this is not strictly correct.

Mechanical stokers operating in conjunction with self-contained forced draught, or induced draught, must of necessity be much more flexible than stokers dependent entirely upon chimney or natural draught, but the most efficient performance of machine fired furnaces is invariably obtained under conditions where the demand for steam is steady.

It should be distinctly understood that the foregoing observations are concerned with mechanical stokers as applied to internally fired boilers, and mainly to those of the Lancashire type.

Having in mind the comparative numbers of water tube boilers and internally fired boilers in use, mechanical stokers have been much more extensively adopted with the former type of boiler than the latter.

Although Lancashire boilers have been made in Great Britain for nearly eighty years past, extraordinary as it may seem, the various makers have never devoted close attention to its efficient firing equipment, either by hand or machine. On the contrary, in the development of the water tube boiler, by the best known makers, very close attention has constantly been given to the problems of firing, and to the most efficient use of every class and grade of fuel.

It is mainly due to this reason that the machine firing of water tube boilers is a record of steady progress, although it must be admitted that for boilers of this type machine firing was and is essential, not only in order to smokelessly burn a wide range of fuels, but also because of the gradual increase in the size and capacity of the boilers, and accordingly the large quantity of coal which has to be burned in a single unit.

In so far as Lancashire boilers are concerned the design, manufacture, and exploitation, both of mechanical stokers and efficient hand fired furnaces, has been left to firms who have specialised in this work. This, to some extent, may be regarded as a reproach upon boiler makers, but it can scarcely be disputed. It is to be regretted that those who have been responsible for the design and manufacture of boilers of such a popular and very extensively used type, have, to a very

considerable extent, never concerned themselves with the vital question of its economic and efficient firing equipment.

Only to a limited extent has this been the case in connection with water tube boilers, but it is only fair to add that by far the most widely used apparatus is the Babcock & Wilcox chain grate mechanical stoker.

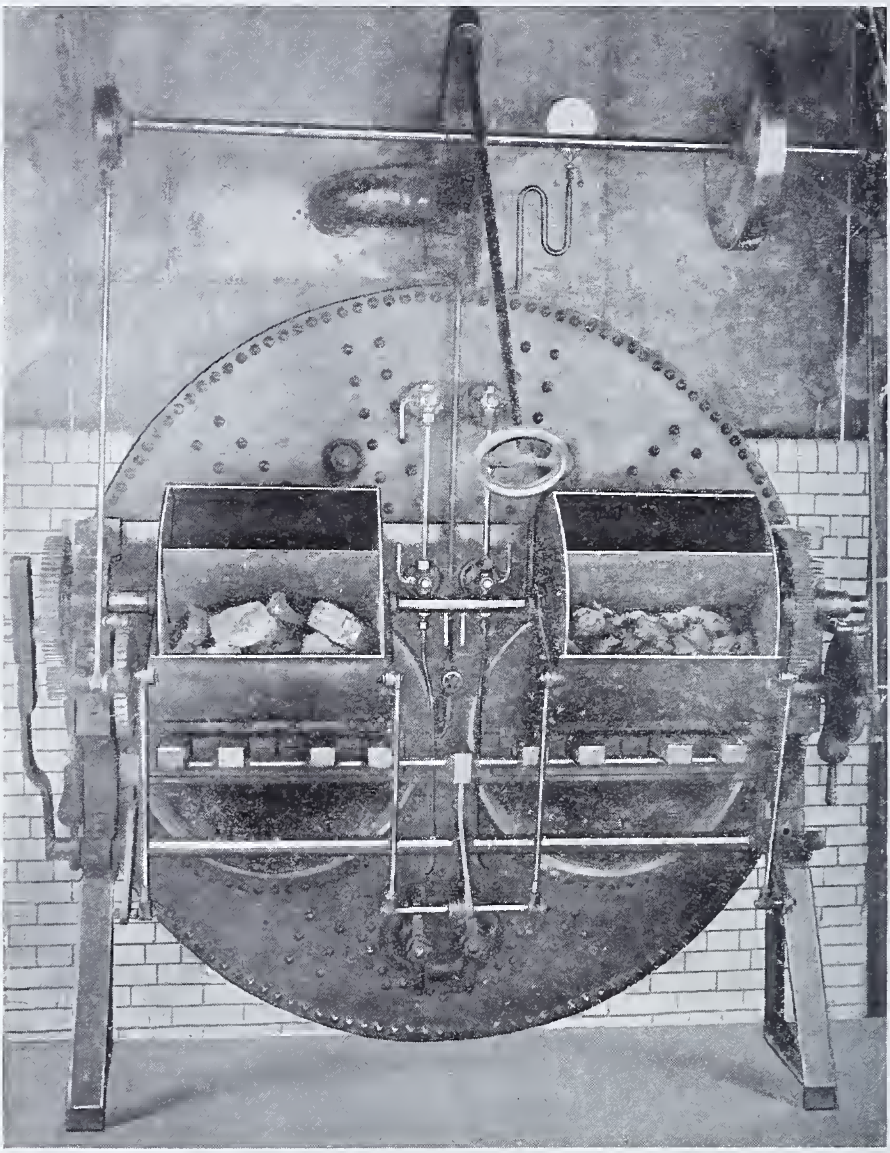


FIG. 112.—AN EARLY TYPE OF MECHANICAL STOKER FOR FIRING LARGE COAL.

The first mechanical stoker of the chain grate type was patented by Mr John Juckes in 1841, of which it is recorded that it was completely successful in the prevention of smoke, while also showing a substantial improvement in fuel efficiency over hand firing. Twenty-five years since the author saw some Juckes stokers in operation under Lancashire boilers in Glasgow.

The mechanical stokers now in use may be broadly divided into two distinct groups or classes, viz. coking stokers and sprinkling stokers, the former type embodying, as its name implies, the coking principle, and the latter type the mechanical sprinkling or spreading of the fuel over the grate.

In Fig. 112 is shown a simple type of mechanical stoker for the firing of lump coal, which was used in Scotland some thirty years since. It is believed that this is the only mechanical stoker which has ever been used for firing large coal. While no records are available as to its performance it may be assumed that the only advantage realised would be in the elimination of hand firing, as it would obviously be impossible to keep the grate adequately covered, and to prevent a very considerable excess of air passing through the grate.

Among the earliest, and still one of the most successful stokers of the coking type, is the well-known Vicar's mechanical stoker, which was orignially patented in 1867. One distinctive feature of this mechanical stoker is the use of unusually short grates.

Other well-known mechanical stokers of the coking type are the Bennis, Hodgkinson, and Meldrum, and of the sprinkling type the Bennis, Proctor, Triumph, and Meldrum. These are the makes of mechanical stokers which are now mainly used with Lancashire and internally fired boilers. Stokers of these makes and types are no longer used to any extent with water tube boilers.

In so far as mechanical stokers of the coking type are concerned the principal points of difference between the various makes referred to are in the details of the coal feed and in the design and type of grate used. Further, some stokers are operated under natural or chimney draught only, others embody self-contained forced draught, which is usually provided by means of steam jet blowers.

Similarly with mechanical stokers of the sprinkling type, the essential and important points of difference are precisely the same, mainly affecting the coal feeding mechanism, the design and arrangement of the grate, and also the air supply.

The Bennis Coking Stoker.—The Bennis coking stoker, illustrated in Fig. 113, comprises a coal feeding machine, furnished with hoppers (*a*) into which the fuel is fed. Duplicate feed boxes (*b*) are placed beneath the hoppers and over the fire doors (*c*). The feed boxes are provided with adjustable reciprocating rams (*d*), which supply the coal to the furnace alternatively and intermittently, the fuel being temporarily carried on supplementary coking bars (*e*) on its way to the main compressed air furnace bars, each with its independent air supply. Between the feed boxes (*b*) is a sight hole, through which the condition of the fire can be observed.

The feed rams are reciprocated by means of levers depending from a rocking shaft (*f*) operated from the gear feed box. The length of the rotary movement imparted to the rocking shaft is regulated by means of a large hand nut next to the gear box. This regulation of the length of the stroke of the rocking shaft regulates the length of stroke of all the rams operated from this shaft.

In addition to this regulation a fine screw operated by a hand nut in a convenient position is provided to each reciprocating ram (*d*), so that small differences in the burning capacity of any part of the furnace due to variations of draught may be

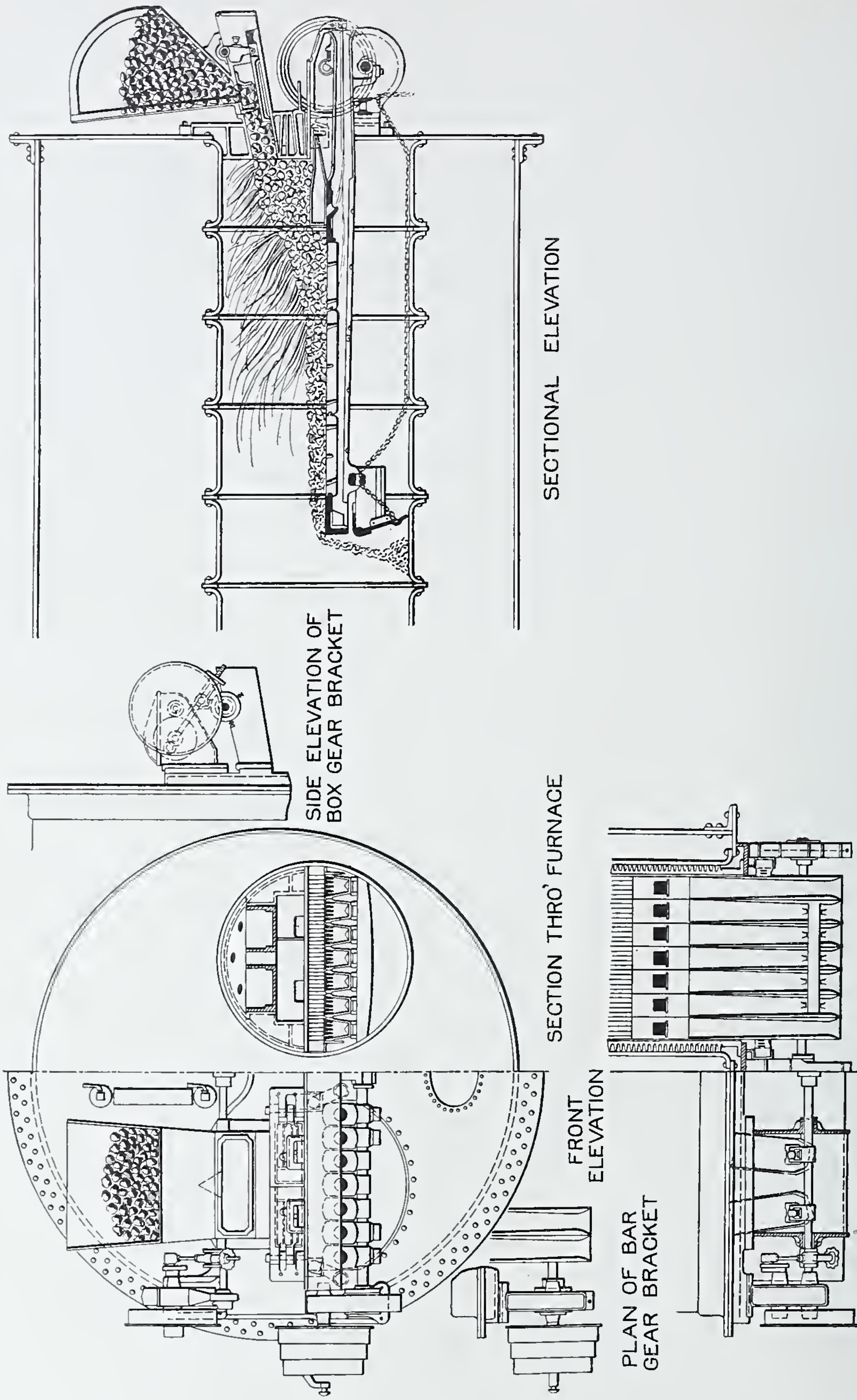


Fig. 113.—The Bennis Coking Stoker and Compressed Air Furnace, application to a Lancashire Boiler.

met. The coal feed is thus adjustable and controllable. Beneath the feed boxes fire doors (c) are provided, so designed that air circulation takes place through them under pressure.

The burning capacity of a coking stoker grate is determined and limited by the speed at which the fuel ignites as it leaves the feed boxes. If large burning capacity is desired means must be provided for increasing or speeding up the ignition capacity, beyond that which normally occurs when fresh coal is introduced in front of a bright and active fire.

In this respect the Bennis stoker is very satisfactory; below the fire doors (c) a series of stationary coking bars are provided, having air spaces along their upper surfaces, and also at the ends. Air under pressure is forced through these bars, being picked up from the hollow grate by means of a dipper (j) carried by the hollow furnace bars.

A higher air pressure is needed here than in the furnace or grate bars, because at this point the body of fuel is thickest.

The air passes through the air spaces in the coking bars (e) into the mass of coking fuel, and assisted by the circulation of air from above, considerably expedites the ignition.

It will be observed that the level of the coking bars is several inches above the grate level; the object of this is to partially break up the coked fuel so that it may travel forward in a more open condition. This is a point of some importance, as with good coking fuels, with the coking space and grate practically on the same level, there is a constant tendency to carry forward masses of coked fuel; under such conditions it is extremely unlikely that the grate will be thoroughly covered, or that the air will penetrate the mass of fuel evenly.

Below the coking bars is the furnace or grate, comprising self-cleaning compressed air bars. The bars all move forward together for a distance of about 2 in. and are withdrawn singly by means of a 4-in. wide cam, on a transverse shaft.

To reduce the wear these cams are made the full width of the bars. The motion of the bars is so arranged that each bar on its outward travel moves between two other bars, which are for the time being stationary. In travelling from the front of the fire to the back the coal ascends an incline of about 3 in. The clinker and ash is slowly carried to the ends of the bars, which are provided with a dumping block (1) for their preservation, and falls over into a closed chamber.

The grate is made up of hollow firebars or troughs, these being covered by short interlocking bars which can be individually replaced without affecting the other portion of the grate.

The driving gear for the coal feed is distinct and separate from the gear which operates the grate. In both cases the power is obtained by belt drive from a line shaft, usually placed immediately over the front of the boiler.

The feed gear comprises a pair of spur reduction gears contained in a totally enclosed oil bath casing, with a belt pulley at the side. At the inner or stoker side of the casing an eccentric disc is provided with rod and oscillating lever on to the rocking shaft, and a reeiprocating motion of the latter is thus obtained. A hand

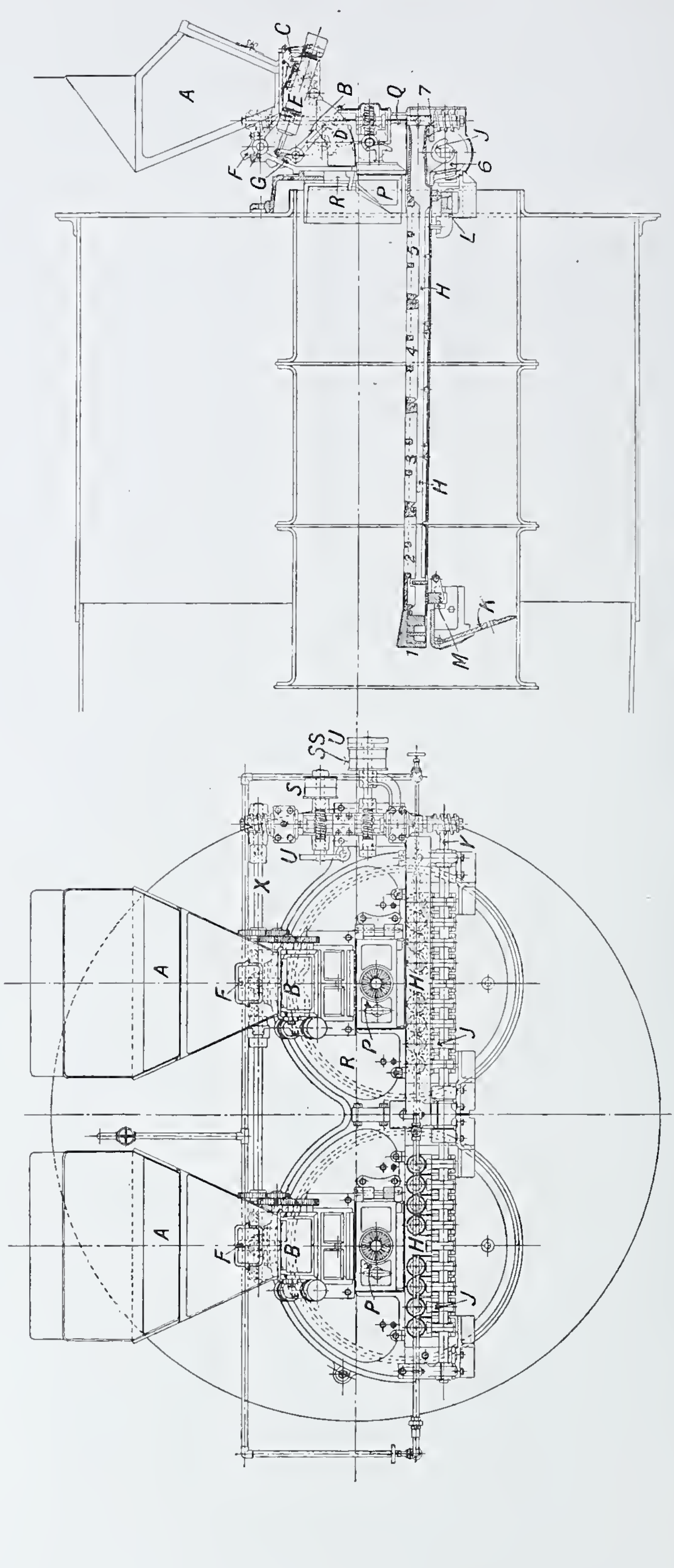


Fig. 114.—The Triumph Sprinkler Stoker.

adjusting nut provided on the connecting rod enables the length of the stroke of the rocking shaft to be varied to feed any desired quantity, up to the maximum capacity of the stoker.

The drive for the furnaces is entirely independent, an enclosed gear box being provided, containing a set of spur reduction gears, the slow speed shaft of which is coupled direct to the shaft driving the bars. A two-speed belt pulley is provided so that the speed can be regulated to suit different fuels. A disengaging clutch in the belt pulley enables the motion of the bars to be entirely stopped. The clutch is designed so that it can be thrown in or out of gear with very little effort.

Air is forced through the grate bars by means of steam jets, the steam being superheated by means of a side flue superheater.

The Triumph Sprinkler Stoker.—The Triumph sprinkler stoker is illustrated in Fig. 114. As designed for the burning of low grade fuels it embodies a forced draught furnace of the steam jet blower type, the grate comprising trough bars fitted with renewable grids having graduated air spaces which form the surface of the grate.

The cams for the reciprocating movements of the grate are so designed that both the backward and forward movement of each firebar is provided by the same cam.

These are slipped loosely on to a square forged steel shaft and can be easily removed and replaced.

The coal being fed into the hoppers (A) gravitates into a feed box containing an adjustable pusher slide (C), which receives a rectilinear reciprocating movement by means of a crank worked at a speed suitably accelerated by a triple train of straight gearing from the upper shaft (x).

At regular intervals this slide, which is in the form of a step plate occupying the full width of the feed box coal feeder, pushes forward a small charge of coal, which falls in front of the V-shaped renewable shovel (D), which is held by strong forged steel arms on each side of the feed box, keyed on to an axle shaft with wide bushed bearings. On the shaft (x) is keyed a four-armed chilled cam (F), the projections of which severally engage an hardened steel trigger (G), keyed in the centre of the shovel axle shaft; this action raises the attached shovel arms to their backward position, ready to strike. A prolongation of the shovel arm in the form of a crank lever is connected to a powerful recoil spring (E), which is compressed during the backward movement of the arms given by the cam.

At the moment of release the spring drives the shovel smartly forward, scattering the charge of coal over the surface of the fire; the shovel then returns to its back position, and the slide (C) again charges it with a definite quantity of fuel. The slide can be thrown out of gear so that the feed to either furnace may be shut off independently, and the traverse of the slide may be regulated so as to permit of more or less fuel being fed as required.

In order to distribute the fuel uniformly on the grate the cam (F) has four arms of unequal length, which successively compress the spring more or less, and accordingly vary the throw of the shovel.

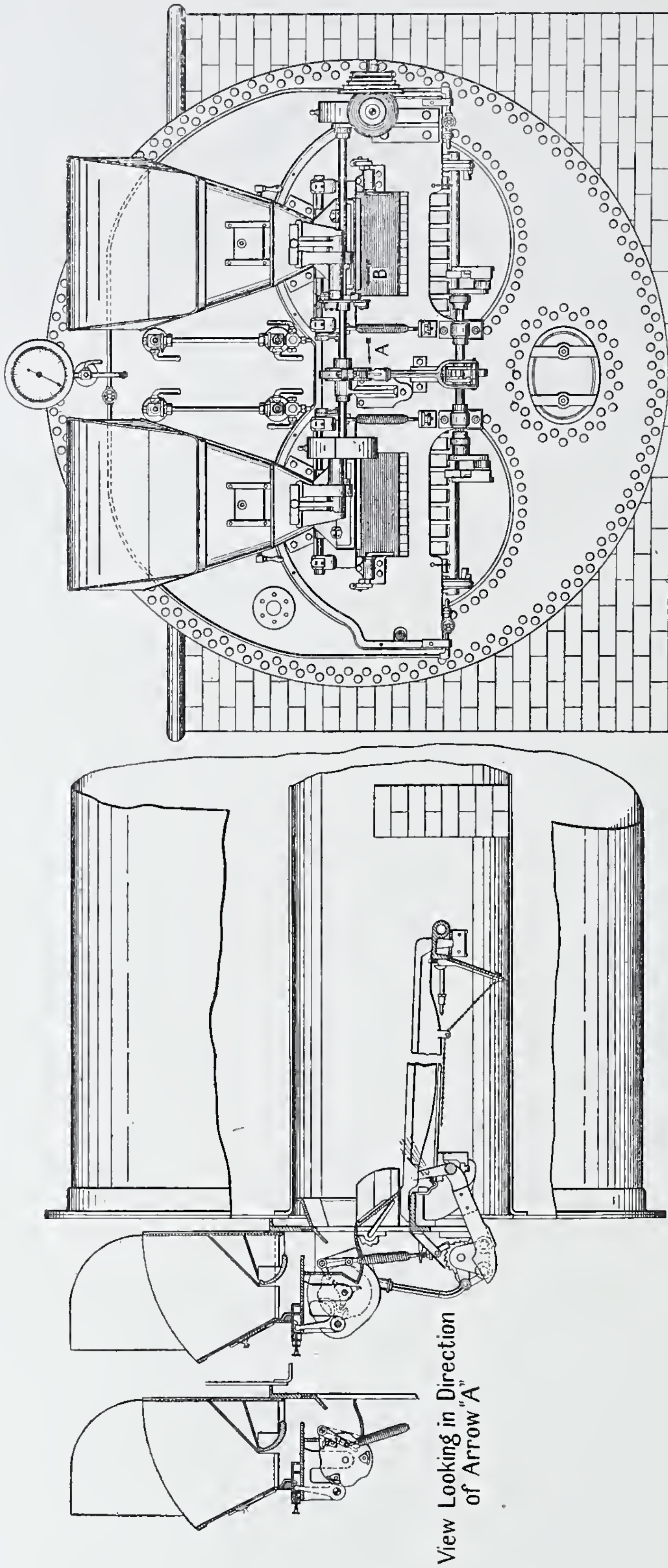


FIG. 115.—THE PROCTOR SPRINKLER STOKER.

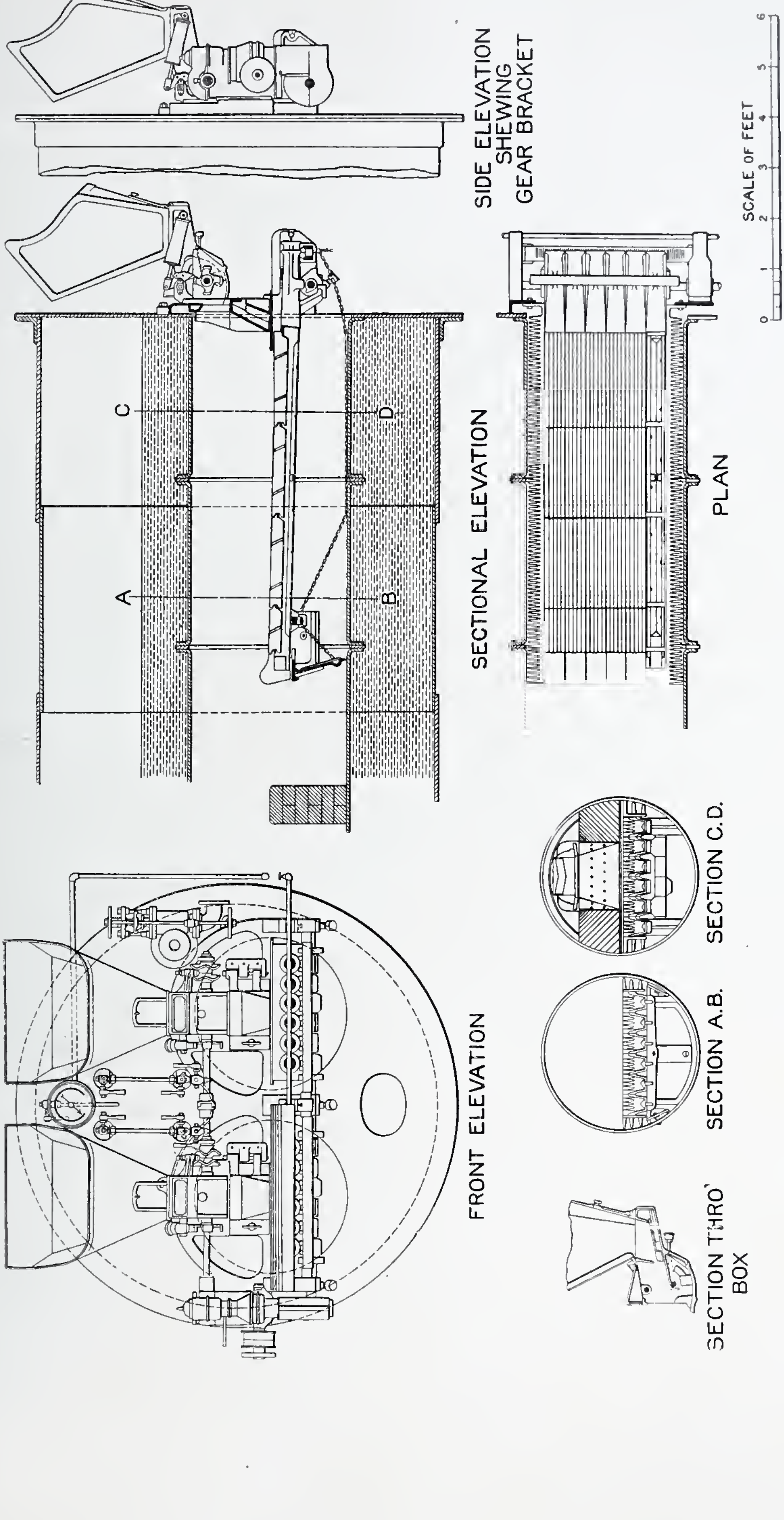


FIG. 116.—THE BENNIS SPRINKLER STOKER.

The stoker is driven from a countershaft in a suitable position above the boiler. The driving-gear bracket is bolted to the extended furnace front plate (R) and is fitted with two separate pulleys, taking the belts from the countershaft and driving respectively the feed motion and the firebar motion. The pulleys by means of vertical screw gearing set in motion their respective shafts having similar gearing at the ends, transmitting a slow rotary motion to the horizontal shafts. By this

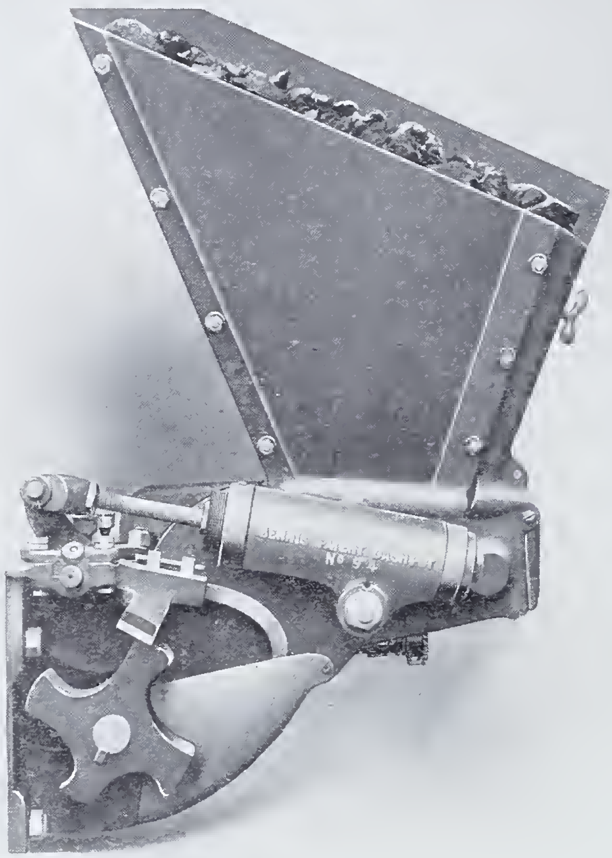


Fig. 117.—Side View of Throwing Box, Bennis Sprinkler Stoker.

arrangement both the feed motion and the firebar motion can be used either independently or in conjunction, and the ratio of speed of either motion can be adjusted to suit the fuel to be used.

The Proctor Sprinkler Stoker.—The Proctor sprinkler stoker or the well-known radial arm shovel type is illustrated in Fig. 115, which shows a stoker of the standard type, for use with natural draught or induced draught. For the utilisation of low grade or waste fuels, while induced draught is sometimes employed, the stoker is usually designed for use in conjunction with the zenith forced draught furnace

made by Messrs W. Whittaker, Ltd., which arrangement provides for a self-contained forced draught equipment.

The Bennis Sprinkling Stoker.—The Bennis sprinkling stoker is illustrated in Figs. 116 and 117. From the hopper, which has a capacity of about 3 cwts., the fuel passes to a cast-iron feeding-box underneath, in the interior of which is a simple

Fig. 118.—Battery of Lancashire Boilers at a Birmingham Works equipped with Bennis Sprinkler Stokers and Compressed Air Furnaces.

form of pusher plate with an adjustable reciprocating motion. The fuel falls in front of the pusher plate and is pushed over a ledge formed by the bottom of the feeding-box.

The weight of fuel so pushed over is regulated by means of an adjustable cam on the driving shaft so that the rate of feed can be seen by noting the position of the cam. By turning a hand nut the coal feed can be graduated over a wide range.

Falling on to a flat plate called the shovel box, the fuel is projected into the fire at intervals by means of an angular shovel which is so arranged as to sprinkle the fuel over the entire width of the grate. A side view of the throwing-box is shown in Fig. 117, with pneumatic cylinder, variable throwing cam, shovel arm connection, and renewable tripper.

The shovel is actuated by means of pneumatic gear, which consists of a long coiled spring enclosed in a cylinder and pressing on a piston, the function of the

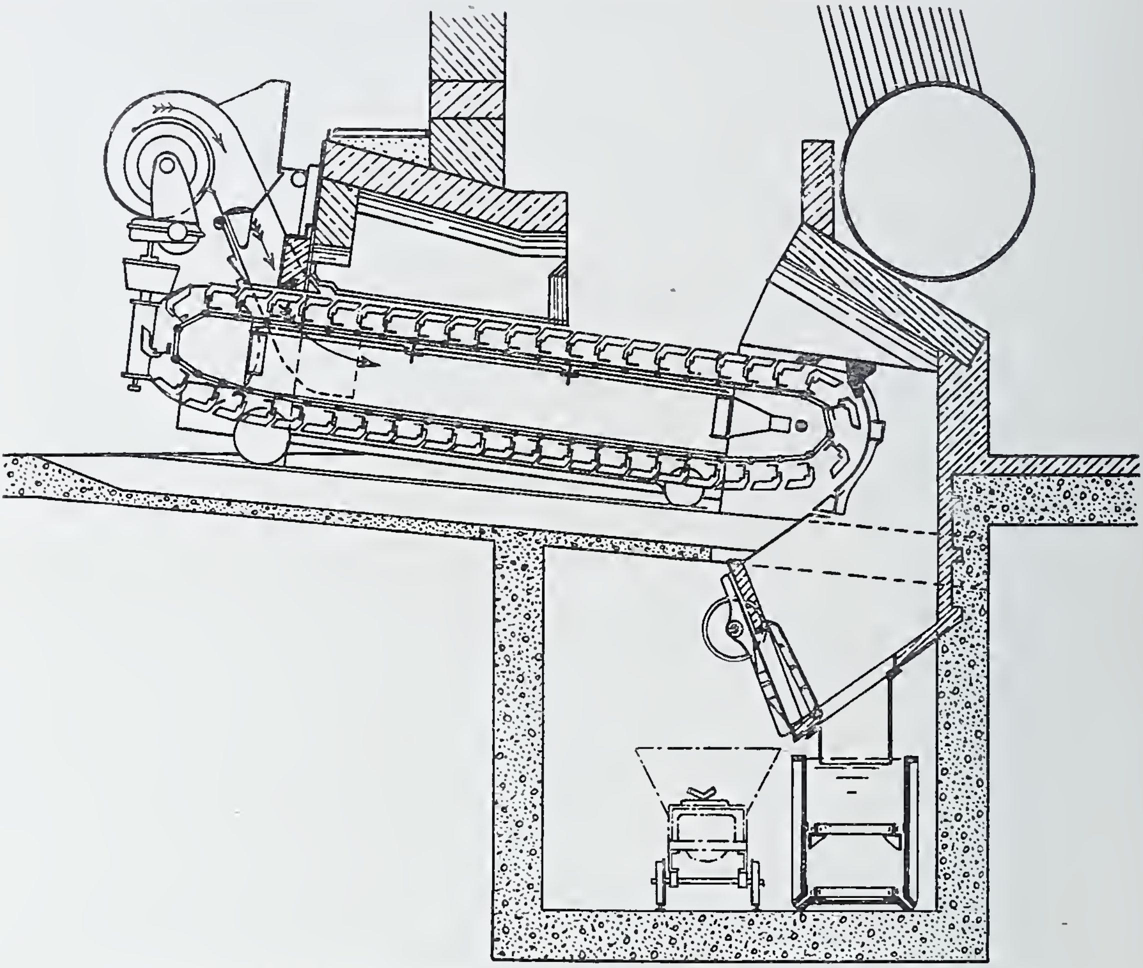


Fig. 119.—The Self-contained Impelled Draught Travelling Grate Stoker.

spring being to propel the shovel forward. Any remaining momentum is taken up by an air cushion to avoid shock or jar to the boiler front.

The rotating tappet which draws back the shovel has four varying lifts. The effect of this is to scatter the fuel over the fire in four zones of feed, each about 18 in. long, the object of this is to secure incandescence between the periods of feed.

The shovel arm is attached to a steel rocking shaft which rests in three replaceable external bearings. The ends of the steel shaft are turned to a sliding fit. The shaft is made with two projecting arms of channel section, one down each side of the box, which form the seatings to carry the shovel arm.

The shovel arm is of rectangular section and is made from fine open hearth acid steel, and is bent round and carried up both sides of the box, the upper ends being fitted into the projecting arms of the shovel shaft, where they are secured by means of screws and locking pins.

The grate of this type of stoker is identical with that already described in connection with the coking stoker.

Fig. 118 illustrates a large battery of Lancashire boilers at a Birmingham works, equipped with Bennis sprinkling stokers and compressed air furnaces.

The Self-Contained Impelled Draught Travelling Grate Stoker.—The self-contained impelled draught travelling grate stoker, made by The Underfeed Stoker Co., Ltd.,

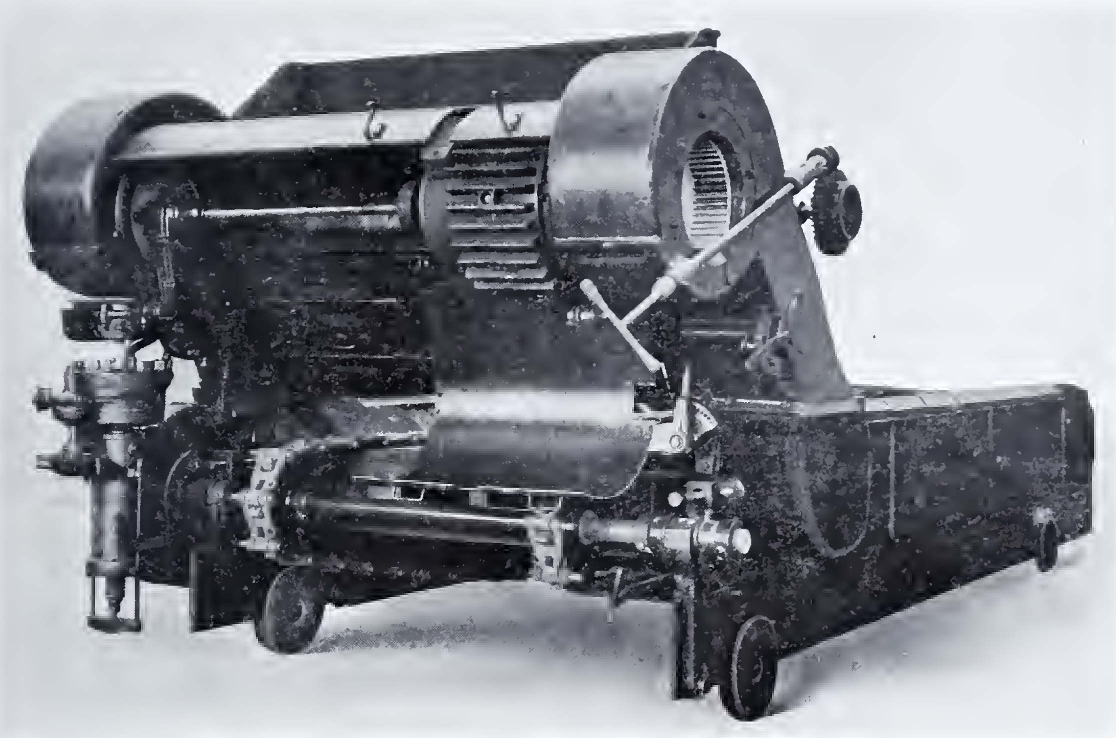


Fig. 120.—The Self-contained Impelled Draught Travelling Grate Stoker.

and illustrated in Figs. 119 and 120, has been extensively adopted for the firing of water tube boilers. Evaporative tests with stokers of this type burning coke breeze are given elsewhere.

The design of this mechanical stoker is novel, embodying in the one unit the stoker, motor-driven forced draught fans, and the stoker drive.

This type of stoker is in use with a wide range of fuels, and its flexibility and efficiency, even with very low grade fuels, is remarkably high.

The stoker comprises an endless moving grate of box-shaped firebars mounted upon chains, the links of which engage sprocket wheels, which are rotated by a novel mechanism, receiving power from a suitably placed driving shaft. The caps of the firebars are perforated or slotted for the delivery of air into the fuel.

The grate is made up of a plurality of moving box-shaped sections which gradually open as they pass around the rear sprocket wheel, close again underneath, open again at the front sprocket wheel, and finally close when passing under the hopper, presenting a flat fire surface.

The air supply from the forced draught fans arranged at the ends of the hoppers enters through rectangular boxes at the sides of the stokers, and flows respectively into longitudinal air chambers, one on either side of the stoker.

These air chambers have their upper surfaces inclined at an angle of approximately 30 degrees, and are provided with longitudinal openings for the delivery of air into the open ends of the box-shaped firebars.

This arrangement provides for progressively varying the quantity of air admitted to different parts of the fuel bed, so as at the front, where the fresh coal is being fed

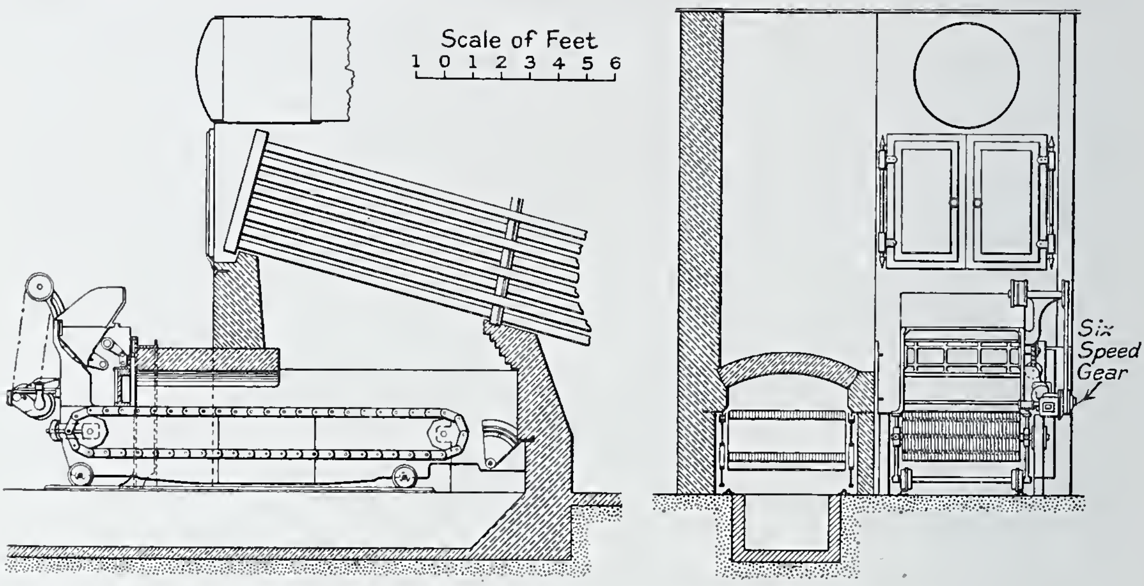


Fig. 121.—The Bennis Chain Grate Mechanical Stoker.

and the resistance to air admission is greatest, the maximum quantity can be supplied, while at the back, where the fire is thin and open, the minimum of air is admitted.

The control of the supply of air to the fire is arranged by the movement of hinged triangular shaped dampers. These dampers can be placed in any desired position by the movement of operating handles, with the result that the quantity of air delivered can be regulated, and can thus be progressively varied from the front to the rear of the stoker.

The fuel is delivered in the ordinary way to the hopper, from which the quantity fed upon the grates is regulated by a sliding shutter which is raised or lowered by a rack and pinion.

The machine is mounted upon four wheels, and can if so desired be withdrawn in the same manner as a chain grate stoker.

Although usually arranged with self-contained impelled draught, this stoker

may be operated either under natural or induced draught if so desired. For the larger boiler units, in connection with which more than one stoker is used, each stoker being self-contained, it is possible if necessary to shut a stoker down independently of the other stokers.

The Bennis Chain Grate Stoker.—The Bennis chain grate stoker, illustrated in

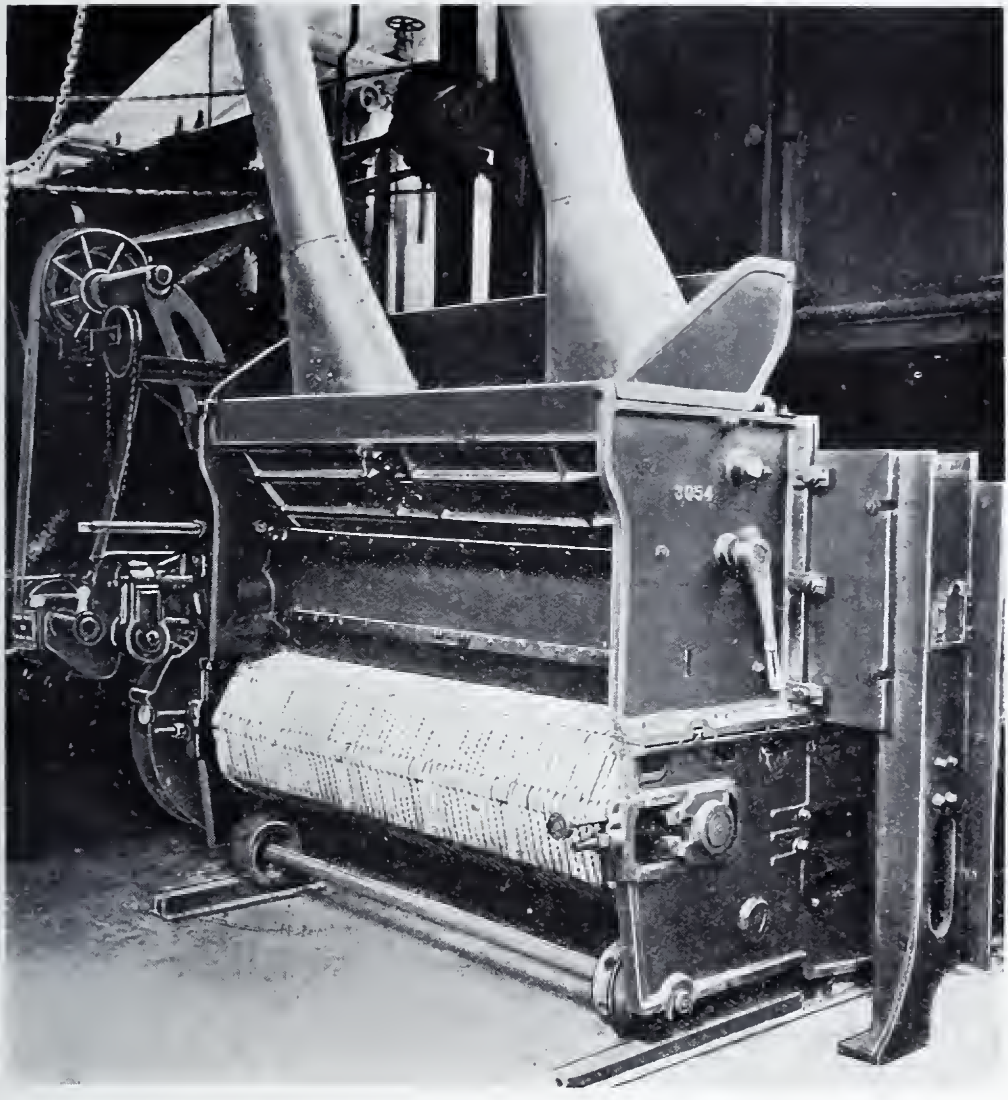


Fig. 122.—The Bennis Chain Grate Mechanical Stoker applied to a Babcock & Wilcox Water Tube Boiler.

Figs. 121, 122, and 123, embodies several features of interest in its design, and has been extensively adopted.

With this stoker both the sides and the back of the hopper are hinged so that they can be dropped to permit of the tube doors above being opened; the back of the hopper is also sealed to prevent air leakage to the furnace. The hopper is provided with a cut off valve and operating arm so that the supply of fuel from

the hopper to the grate may be cut off, this valve being so arranged that in cutting off the supply of coal it travels with the flow.

At the back of the hopper the fire door slides vertically; it is lined on the inside with refractory bricks. These doors can be adjusted to any height by means of suitable mechanism so as to regulate the depth of fuel which travels on to the grate. An indicator is provided on the side showing the height in inches of the fire door above the grate level, thus giving the depth or thickness of fuel which is being fed on to the grate.

The grate frame is constructed of cast-iron, strongly ribbed and fitted with bearings to carry the front and back drums. The frame is bolted together by

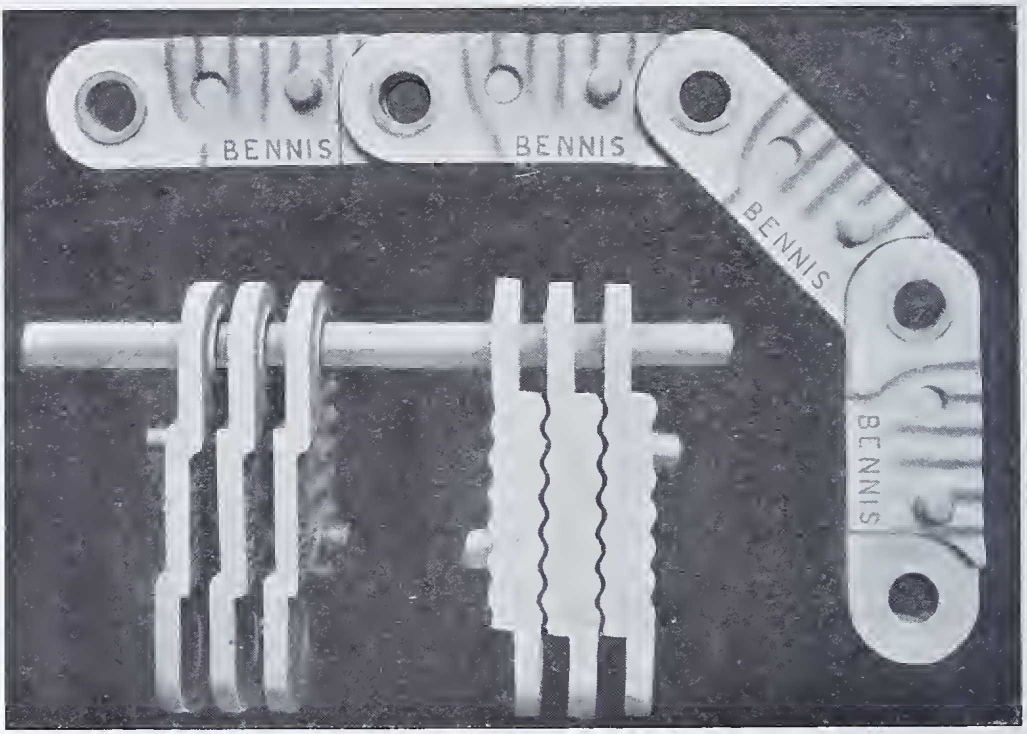


Fig. 123.—Bennis Chain Grate Stoker Links.

channel steel distance pieces and bolts, and is substantially cross braced. The whole structure is mounted upon wheels and can be withdrawn.

The grate links are of what is known as the halved type, being halved at the point of juncture with the succeeding link in the series, which ensures a close joint, and a continuous surface throughout. The air spaces are corrugated.

The speed of grate travel is variable over wide limits, being effected through a grate change gear box with spur wheel gearing, of different diameters, built up in combination with the driving worm and not requiring the use of a key.

The gear is operated by means of a handle arranged to engage with the notches of a gate, and it is impossible to interlock more than one gear at a time. The gear box is enclosed and oil-tight.

A safety friction clutch is provided so that in the event of the torque being increased above what is required to drive the grate under normal conditions, the clutch slips, and the grate is released from excessive driving stresses.

The Bennis stoker is arranged for use under natural, forced, induced, and also balanced draught.

Retort Stokers.—Within recent years mechanical stokers of the retort or archless type have been applied with much success to water tube boilers, among these being the Erith Roe multiple retort stoker, the Riley multiple retort stoker, and the " F " multiple retort stoker, the two last named being of American origin.

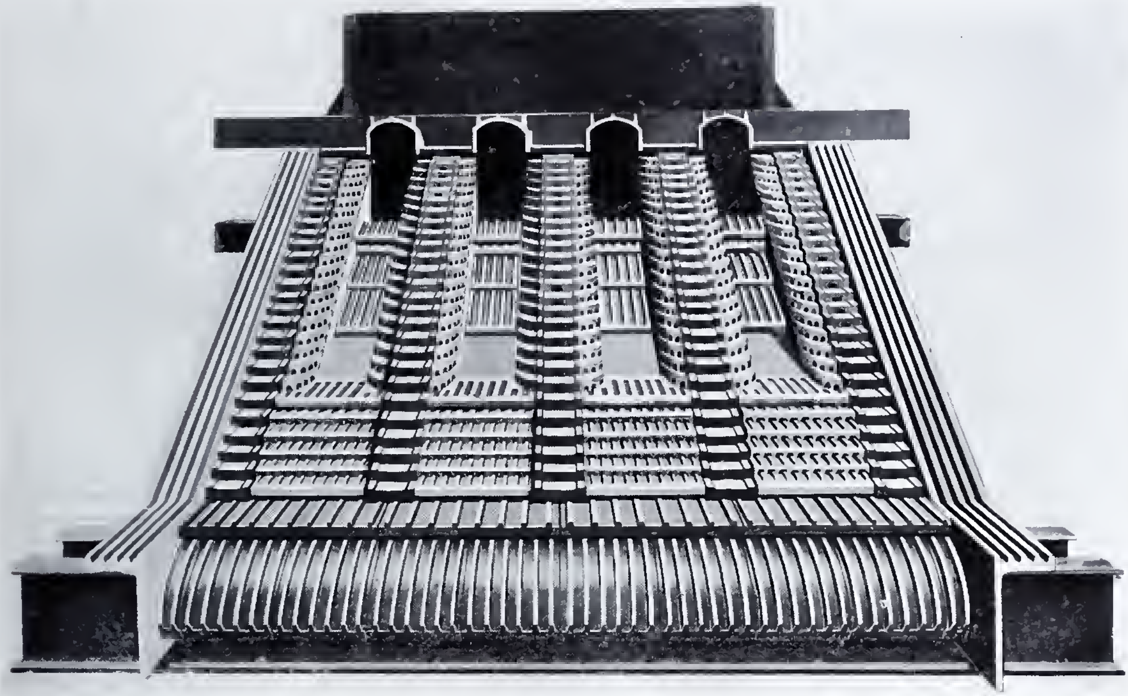


FIG. 124.—THE ERITH ROE MULTIPLE RETORT STOKER, PERSPECTIVE VIEW OF FURNACE.

The outstanding features of mechanical stokers of this type are the simplicity of the furnace brickwork, and the advantage of increased direct radiation from the fire to the heating surface.

The Erith Roe Multiple Retort Stoker.—With stokers of this type, no brickwork arches of any kind are used. Coal is fed from the hopper by the charging action of the rams into a trough or retort containing a reciprocating pusher, which distributes the fuel at its thickest section outwardly over stepped tuyeres and stepped hollow grate bars between the retorts, whence it travels down to, and over, moveable grates (which extend over the whole width of the furnace), eventually reaching the adjustable grate bars, which continuously discharge the ash and clinker into the ash hopper.

The stepped hollow grate bars between the tuyeres of each retort are capable

of reciprocation, and air at low pressure is admitted through them to the burning fuel. While the retort sides and tuyeres are stationary, the reciprocating movements of the stepped hollow grate bars, being independently adjustable, transmit the required degree of sliding motion to the fuel, so that even where the fuel supply varies from time to time, the formation of masses of fused clinker is prevented from accumulating to any serious extent, the fuel being steadily advanced under control, by the combined action of the pushers in the bottoms of the retorts, and the reciprocating stepped hollow grate bars, reaches the moving extension grates,

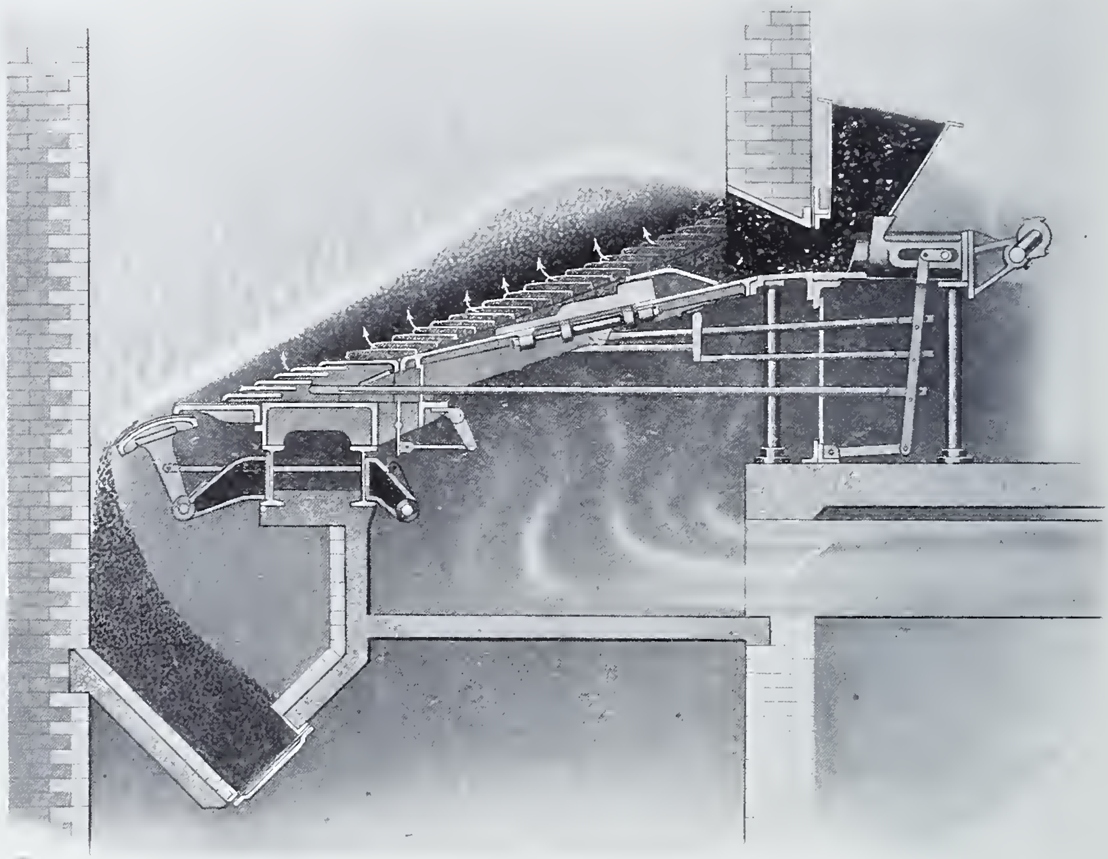


Fig. 125.—The Erith Roe Multiple Retort Stoker, Longitudinal Sectional View of Furnace and Stoker.

when combustion is almost completed, and on these moving grates combustion is finished, leaving the incombustible to be automatically discharged over the ash bars into the hopper.

A unique feature of this stoker is the provision for three independently controlled stages of combustion, viz. a primary stage in which air is admitted at full pressure into the thickest portion of the fuel bed ; a secondary stage in which a controlled supply of air at reduced pressure is introduced into the partially burnt fuel travelling down the stepped surfaces between the retorts ; and a final stage where low pressure air is distributed through the nearly burnt out fuel travelling over the moving extension grates to the ash hopper.

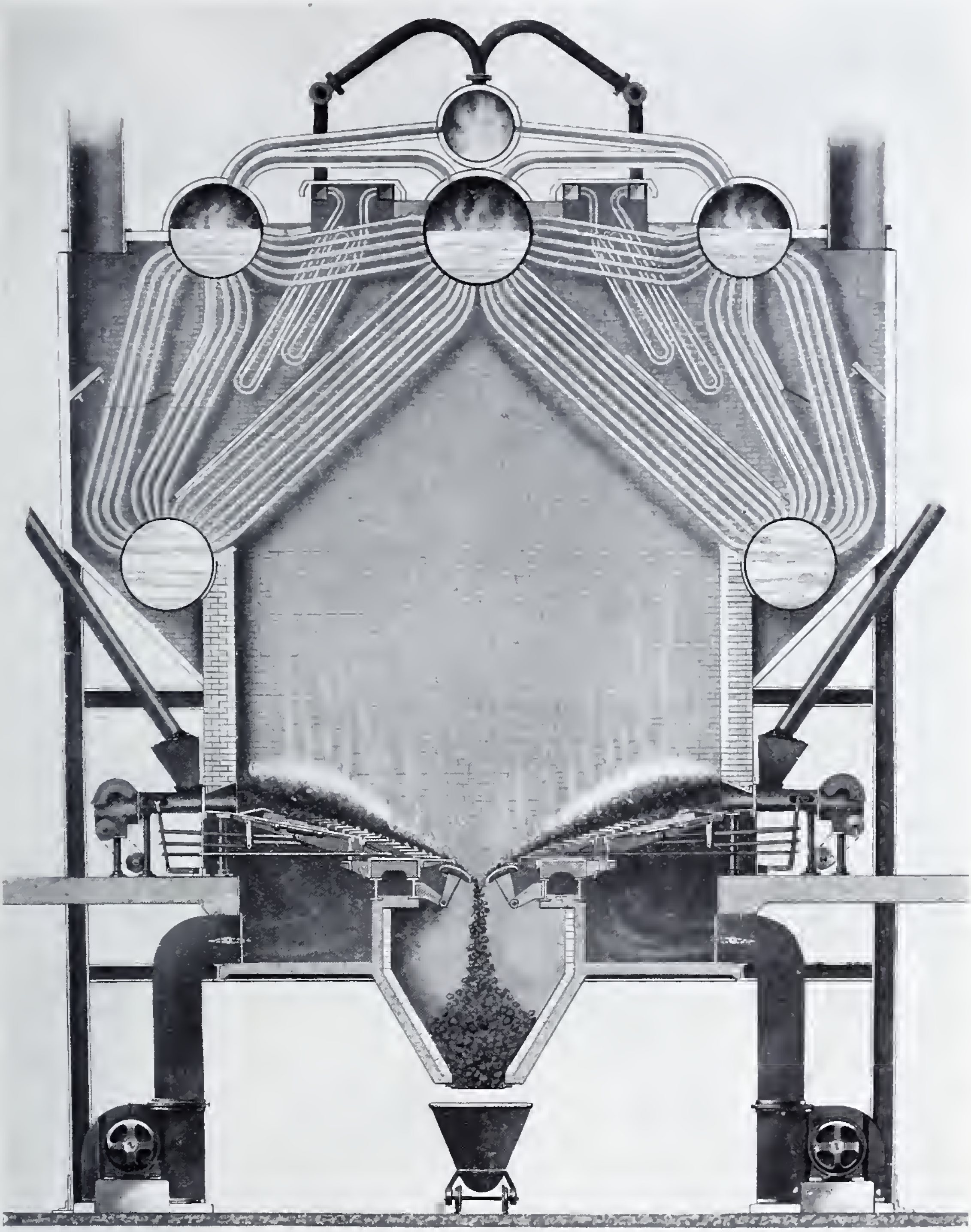


Fig. 126.—Erith Roe Multiple Retort Stokers, Application to a Double-ended Water Tube Boiler.

The fact that with this stoker all moving parts are independently adjustable is a distinct advance in stoker practice and ensures a most useful flexibility in working, and the necessary conditions for utilising a wide range of fuels with efficiency.

Thus the pushers on the retort bottoms can be worked in conjunction with both, the stepped hollow grate bars and the moving extension grates, or either of them, or they may be kept stationary. The stepped hollow grate bars and the extension grates can be quickly adjusted in like manner in relation to each other and the pushers, so that the rate of travel of the fuel bed is under complete control, and can be adjusted to meet the requirements of widely varying fuels without stopping the stoker.

The stoker is built up of units consisting of standardised interchangeable parts, and is of simple design. Any required number of units can be assembled to form a stoker suitable for any width of boiler.

Figs. 124, 125, and 126 illustrate the Erith Roe stoker. Fig. 124 being a perspective view of the furnace, Fig. 125 a longitudinal sectional view of the furnace and stoker. Fig 126 shows an Erith Roe duplex stoker in connection with a large double ended water tube boiler and capable of burning up to 250 tons daily.

Generally the Erith Roe stoker is of massive construction throughout, and is designed to minimise wear and tear; it is motor driven, and the forced draught air supply is delivered by means of a direct coupled motor-driven fan through the air chamber beneath the stoker.

The Riley Multiple Ret rt Stoker.—The Riley multiple retort stoker, which is illustrated in Fig. 127, is widely used in the United States, while in this country a number of installations have been in use for many years past. The external portion of the stoker comprises a number of coal feeding rams, actuated by a heavy slow moving crank shaft, which is driven in sections through double worm speed reduction gears. All gears are machine cut, and the thrust is taken by ball thrust washers.

Any section of the grate can be driven independently of the others, thus enabling the fire to be maintained of an even thickness across the furnace. A shear pin fitted to the connecting rod of each ram prevents damage to the driving gear.

Coal is fed to the rams through the hopper, which is arranged immediately above the ram cylinders.

The furnace part of the stoker consists of a series of retorts corresponding to the rams already referred to. Each retort has a fixed bottom plate and two moving elements which support the fire bed, and which also distribute the fuel throughout the furnace. These moving elements form the sides of the retorts, and carry the moving tuyeres through which the air for combustion is admitted at regulated pressure, the extension grates which admit air at reduced pressure for burning off any combustible in the ash before it reaches the dump, and the rocker dump plates.

The dump plates are hinged, the free ends being carried on rollers, which give the plates a rocking motion, whereby the ash is continuously discharged. The

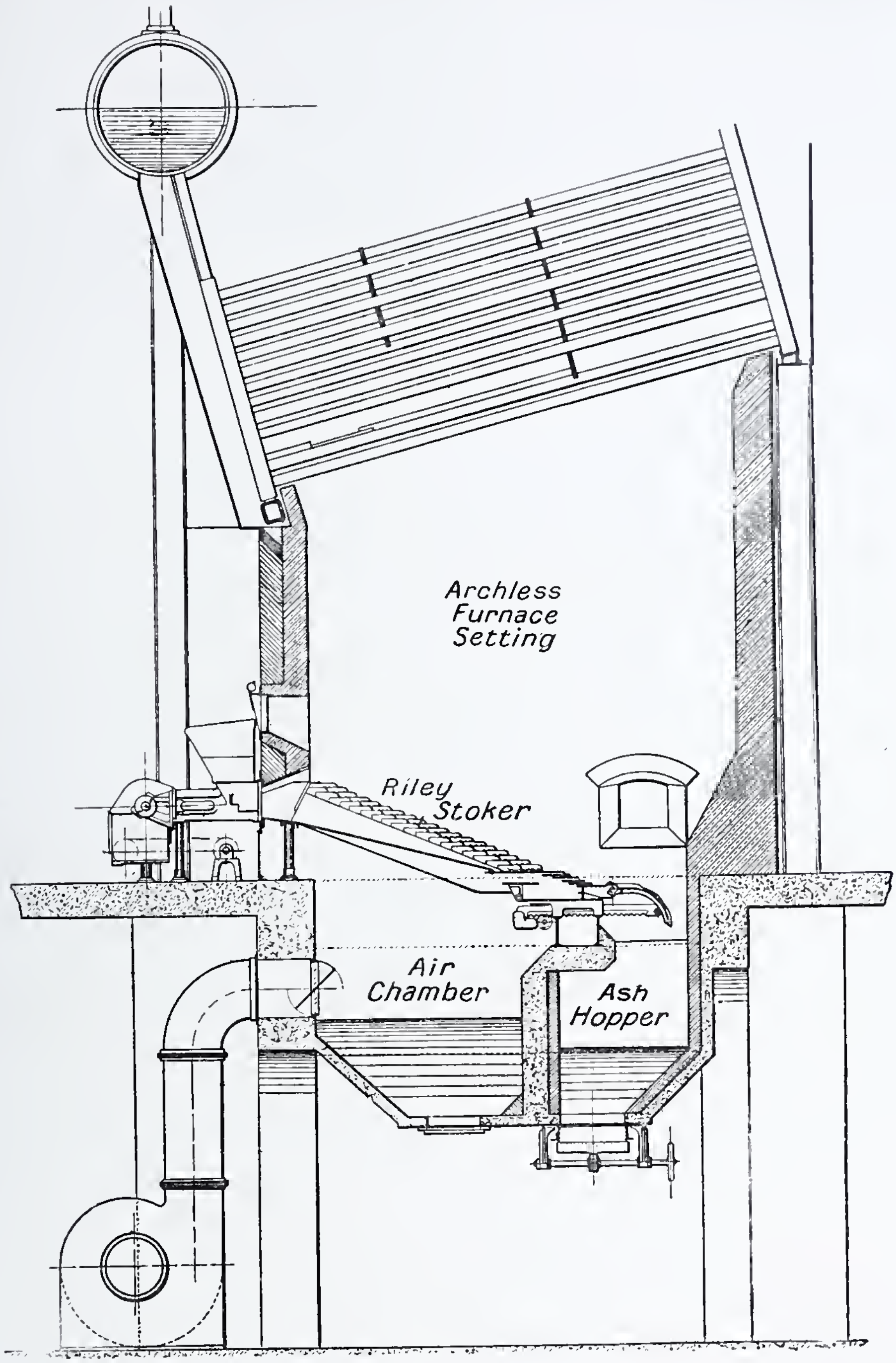


Fig. 127.—The Riley Multiple Retort Stoker.

width of the ash discharge opening is adjusted from the outside, to suit the ash content of the fuel.

No furnace arches are used, the combustion is smokelessly completed within

the thick bed of fuel. Whatever size the furnace may be it is provided with four straight walls only, the entire surface of the fire is incandescent and radiates heat direct to the boiler tubes.

In operation the coal is fed to each retort by its own ram and is distributed through the furnace by the moving elements with the Riley conveyor tuyeres. The air chamber under the complete stoker distributes air for combustion through the moving elements. As the fresh coal below the fire bed rises from the retorts, the volatile matter is disengaged, and burned without smoke, by mixing with air in its travel to the surface of the thick fire bed. Air at reduced pressure is admitted through the stepped extension grates, to burn off any combustible remaining in the fuel, before the residue is discharged by the rocker dump.

The "F" Multiple Retort Stoker.—This type of mechanical stoker, which is illustrated in Fig. 128, has been introduced by The Underfeed Stoker Co., Ltd., in order to meet conditions which can be most efficiently met by the under feeding of the coal and the carrying of a thick or deep fire.

The stoker consists of a series of retorts or troughs spaced about 21 in. apart. The coal is forced from the hoppers to the top ends of these inclined troughs by the usual form of ram, the rams being reciprocated by cranks and connecting rods. In wide furnaces the stoker is made up of groups consisting each of several retorts, each group having its own crank shaft.

Each crank shaft is driven by a variable speed gear in such a way that each group of stokers may have the quantity of coal which it feeds varied in relation to any other group. Shearing pins are provided so as to avoid damage to the stokers should any foreign material such as iron become lodged between the face of a plunger and the hopper.

Each ram or plunger is provided with a cross pin and steel yoke, the latter being carried on a guide rod. This yoke reciprocates the auxiliary pushers which carry the coal evenly and positively downward throughout the length of the trough.

The stroke of the lower pushers is made adjustable by means of a shaft located above the retorts (see Fig. 128) which engages or disengages with pawls or dogs attached to the moving rod. This important feature, *i.e.* the adjustment of the travel of the auxiliary pushers, enables the depth of fire at the front or top of the retorts with relation to the depth of fire at the bottom of the retorts to be varied. It also provides for the quick covering of the lower grates and dump grates after dumping. This provision also enables a coke fuel bed to be broken when starting up after banking periods.

The stoker is made in various lengths in order to provide grate areas properly proportioned for the duty demanded, taking into consideration also the character and quality of the fuel to be burned. That part of the stoker within the furnace is inclined generally at an angle of 20° from the horizontal.

To prevent the erosion of the walls, and more particularly the front walls, a row of non-clinkering furnace blocks, forming a part of the stoker, is placed within the front wall in such a way as to be connected with the main air chamber of the stoker, and discharge air immediately over the front of the fire. This air admission

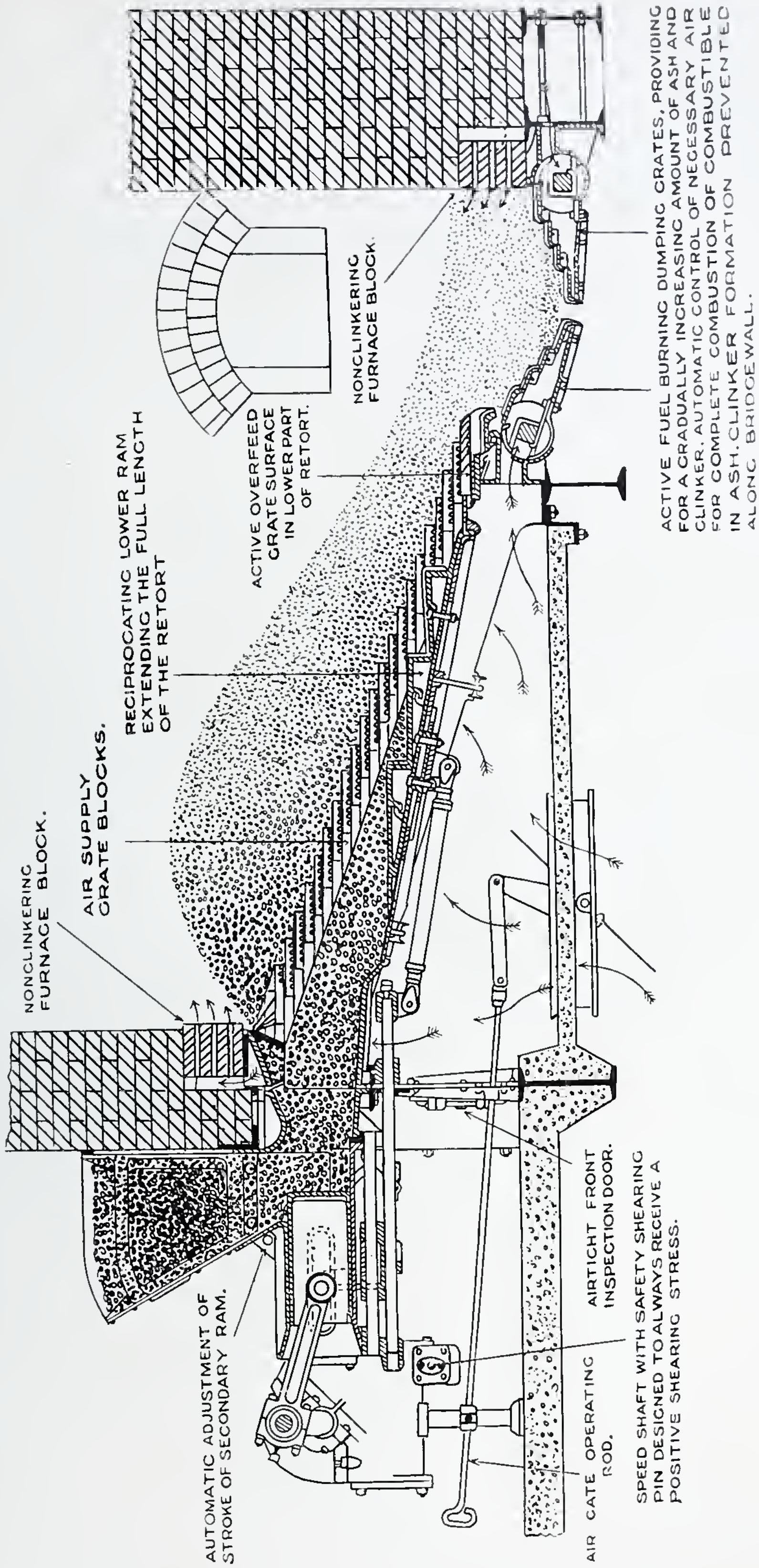


Fig. 128.—The "F" Multiple Retort Stoker.

is also of considerable value in burning carbon monoxide, which with most coals is formed with this class of stoker immediately inside the front walls. The blocks are clearly shown in Fig. 128.

Ample space is provided for the accumulating ashes and clinker and by the arrangement providing for the adjustment of the dump grates, the clinker containing capacity may be increased as it accumulates. The dump plates are actuated by worm and gear, or for very wide stokers, power mechanism may be employed. When the dump grates are dropped the air supply is automatically cut off as shown in Fig. 128.

The tuyeres possess distinctive features. The shape and air distribution, which

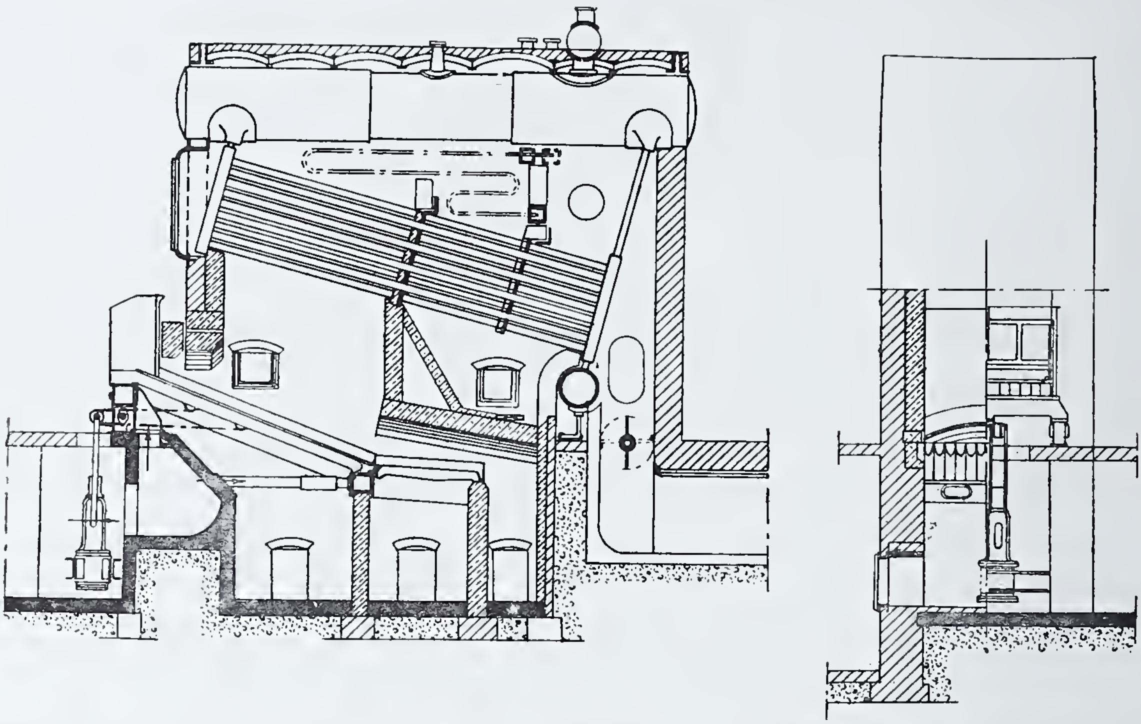


FIG. 129.—THE PLUTO STOKER, APPLICATION TO A WATER TUBE BOILER.

is equal round the entire tuyere, and the large cooling surface are important points in minimising wear, and maintenance cost.

The Pluto Stoker.—The Pluto stoker is a type which has been very successful in continental countries in the utilisation of low grade fuels and is of Dutch make. This type of mechanical stoker is referred to in Chapters III. and IV., where details of evaporative tests with brown coal, lignite and peat are given. The application of the stoker to a water tube boiler is shown in Fig. 129.

The grate is in two sections, one slightly inclined downwards from the hopper, and the other towards the back end horizontal. Both sections of the grate are formed of long narrow bars having a reciprocating motion.

The inclined grate bars consist of troughs with comparatively restricted air spacing, machined on both sides and on the sliding surface, the upper portion or fire surface of the trough is filled with small and easily replaceable standard fire bars.

The horizontal grate bars are of similar construction and engage with the inclined bars in their reciprocating movement. Both the inclined and horizontal grates slide on three cast-iron air boxes.

At each side of the grate throughout its length in front of the brickwork are fitted steel side plates. These side plates keep the moving bars of the grate close together and at the same time prevent the flow of excess air.

The reciprocating movement of the grate is provided by means of a rocking driving shaft provided with levers and connecting rods, each bar being driven separately.

The rocking driving shaft is actuated by means of a steel arm connected to hydraulic driving gear, so that the speed and amount of travel of the grate bars can

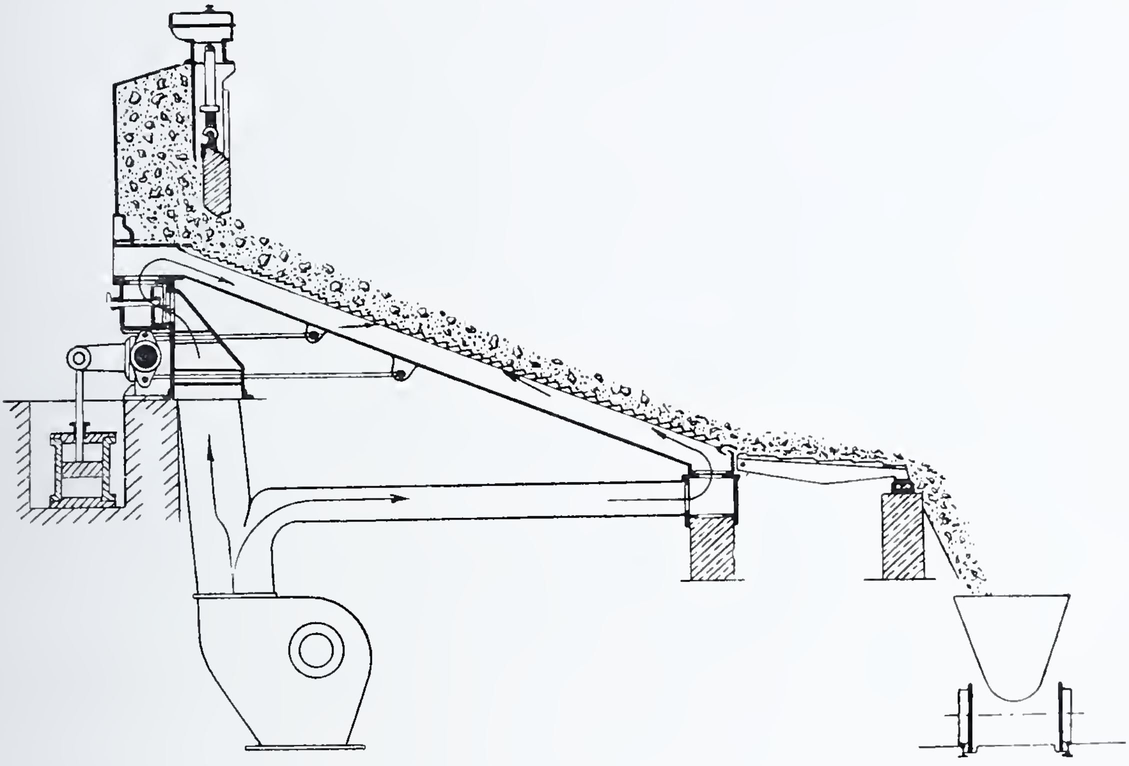


Fig. 130.—Arrangement of an Air Supply to a Pluto Stoker.

be easily adjusted. For most ordinary installations the boiler feed pump may be used for the hydraulic driving gear, but for large installations special pumps are provided.

If desired the driving gear may be provided for direct motor drive or a chain drive. The whole of the driving mechanism in any case is arranged at the front of the boiler so as to be easily accessible.

The stoker works with forced draught. The air supply is divided, part passing down through the inclined trough bars and issuing beneath the fire, through the small fire bars which form the upper portion of the trough.

The remainder is led under the horizontal section of the grate and through

the ash bars. The air supply is regulated by means of adjustable dampers, and the volume delivered at the back end of the grate reduced to the minimum necessary for completing combustion.

If desired, the horizontal section of the grate may be operated under natural draught.

The air ports in the inclined grate are so proportioned as to provide the minimum of air for the upper portion of the grate, but for the most active combustion on the lower portion of the grate, diminishing as the fuel reaches the horizontal bars.

The arrangement of the air supply is shown in Fig. 130. The fire door is of an unusual type and consists of a number of fire-brick lined castings hanging from a horizontal rail, the whole being raised or lowered to provide for different thicknesses of fire by means of a worm and screw gear.

It will be noticed that on the fire side of the fire door a large fire-brick sluice is provided which also may be raised or lowered. This is only fitted in installations

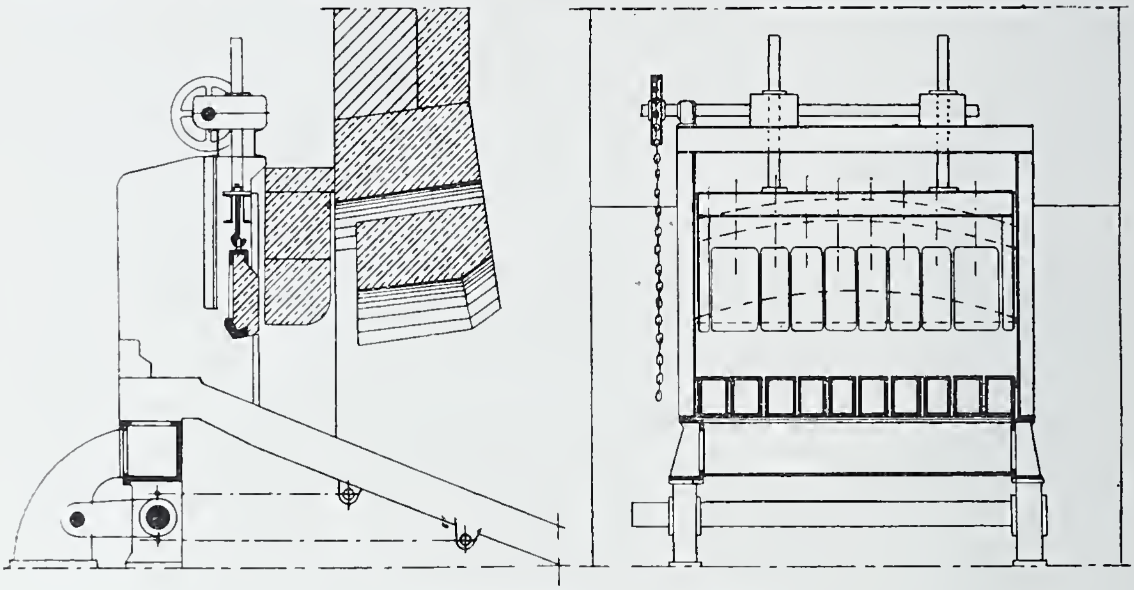


Fig. 131.—Fire Door of Pluto Stoker.

where it is at times required to burn a very low grade fuel. In such cases the sluice is opened and a correspondingly thick fire is obtained. The fire door is illustrated in Fig. 131.

The hydraulic motor is an interesting feature of the Pluto stoker. It can be worked by water either from the boiler feed pumps or from other pumps specially provided for the purpose, the latter provision is usually made in connection with large installations. The pump cylinder is about 12 in. diameter. When the motor is arranged below floor level the drive to the rocking shaft lever is from an extension of the piston rod. In other cases, when the motor is on the firing floor level, head room is saved by a crosshead drive to the lever of the rocking shaft. The main valve of the motor is moved across at the end of each stroke by water pressure controlled by a small pilot valve operated by the pump crosshead arm, the idea

being similar to that on which the design of vertical boiler feed pumps is often based.

The Pluto stoker can be applied to any type of water tube boiler, one of its advantages is the unusually large grate which it provides directly under the boiler, and the small space required in front of the setting. The grates are made in widths ranging from 4 ft. 11 in. to 8 ft. 10 in., and in lengths from 6 ft. 6 in. to 13 ft., measured on the inclined portion. The horizontal ash bars vary in length from 1 ft. 8 in. to 6 ft. 6 in., according to the class of fuel to be burned.

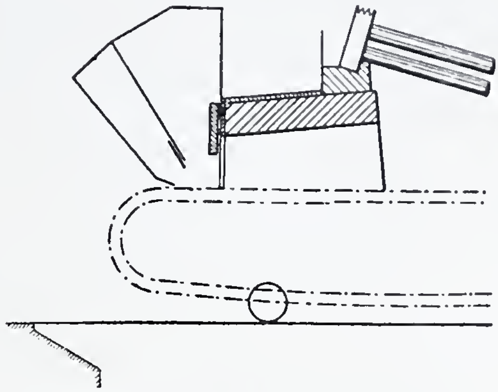


Fig. 132.—The Sandwich System, Application to a Chain Grate Mechanical Stoker.

With machine firing it is the common practice to provide grates of such a length that hand firing over the same length is quite impossible. Chain grates are now made up to 16 ft. in length, whereas a skilled fireman cannot properly cover and keep covered a grate exceeding 7 ft. in length, while preferably the length of a grate for hand firing should not exceed 6 ft.

This wide disparity between the possible grate areas under machine and hand fired conditions is such as to demand for the latter the use of a much superior fuel, while at the same time in all probability reducing the boiler capacity considerably.

The successful application of machine firing to even the largest boiler units, the efficient utilisation of a very wide range of fuels, many of a very low grade and high in ash content, the general reliability of the stokers and their comparatively low cost for upkeep and maintenance, are all factors which much ensure their general and rapid adoption in connection with all water tube boilers.

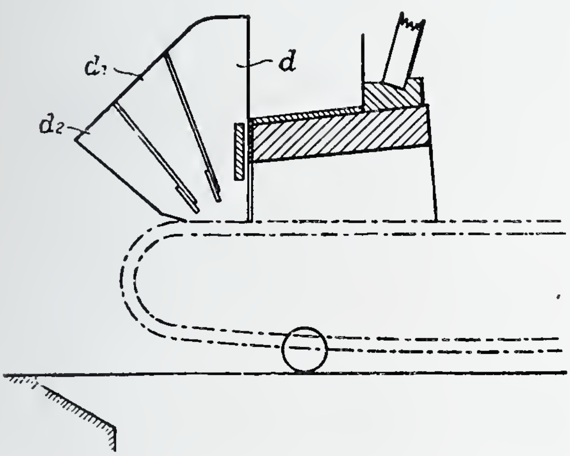


Fig. 133.—The Sandwich System, Application to a Chain Grate Mechanical Stoker.

The Sandwich System of Firing.—An interesting and simple improvement having for its object the simultaneous firing of coke, or coke breeze, and slack coal in superimposed layers, and in variable proportions, is shown in Figs. 132, 133 and 134, which illustrates the application to chain grate mechanical stokers, and underfeed stokers respectively.

This system of divided or auxiliary hoppers providing for the coal to be fed on top of the fuel bed is generally known as the "Sandwich feed." As a simple means of efficiently utilising coke and breeze with coal with machine fired water tube boilers it has been very successful.

The Sandwich system is referred to in Chapter V., while it is usual to provide two compartments only in a hopper; as will be observed upon reference to Fig. 133, the number of divisions may be increased in order to provide for the blending of more than two fuels.

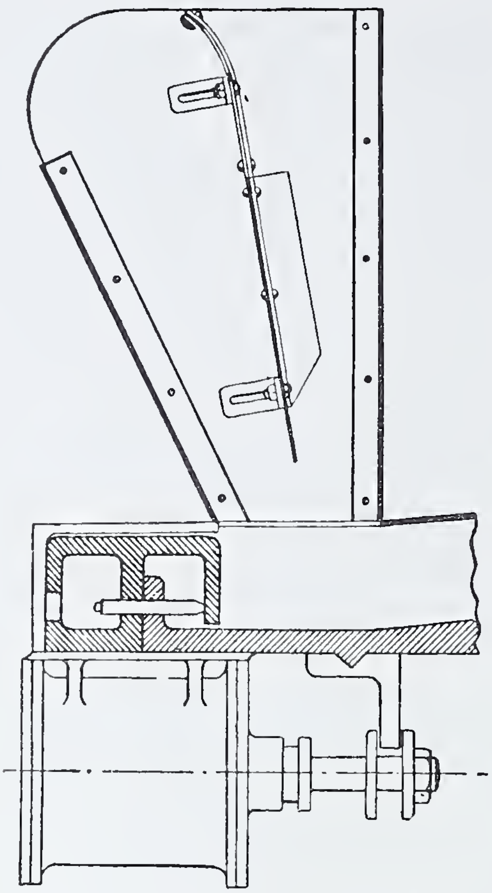


FIG. 134.—THE SANDWICH SYSTEM AS APPLIED TO AN UNDERFEED MECHANICAL STOKER.

The accompanying Table No. 38, giving the minimum and preferred setting heights for boilers of various types, with stokers of a number of types as recommended by the United States Stoker Manufacturer's Association, is of much interest, showing as it does that the demand for increased and ample combustion space is now becoming general.

While some of the boilers and mechanical stokers referred to are not used in this country, the data given in Table 38 is useful and marks a distinct advance.

Hand Fired Furnaces.—While the tendency within the past few years has undoubtedly been towards the more extended use of machine firing, mainly with a view to reducing the cost of labour, and also because of the scarcity of skilled boiler firemen, hand fired furnaces are still very extensively used for internally fired boilers.

The reasons why machine firing has not displaced hand firing to a much greater extent have already been discussed.

If it were practicable upon a large scale and under a variety of working conditions to compare the relative thermal efficiency obtained with hand fired and machine fired Lancashire boilers, there is no doubt that the average record with machine firing would be shown to be higher than hand firing in spite of the fact that mechanical stokers are but rarely operated to the best advantage.

The principal reason for this is that men who have been trained and who are capable of really efficient hand firing are now rarely seen. A skilled fireman is usually worth more than he is paid, and the development of skill has not been encouraged, owing to the general disposition of steam users to regard the work as unskilled, and of comparatively little worth or importance.

In that very valuable work, "Steam Boilers and Combustion,"[1] Mr John Batey refers thus to the necessity for employing trained men:

"Whatever diversity of opinion exists on these matters, there is none in regard to the advantage of working steam boiler plants by brainy men, including

[1] "Steam Boilers and Combustion," by John Batey, pp. 85-86.

TABLE No. 38

Minimum and Preferred Setting Heights recommended by Stoker Manufacturer's Association from Floor to Shell or Header of Boiler in feet and inches

Type of Boilers.		Multiple Retort Stoker.		Side Dump.		Standard Jones.		Murphy and Detroit.		Roney.		Chain Grate.		Forced Draught Chain Grate.	
		Minimum.	Preferred.	Minimum.	Preferred.	Minimum.	Preferred.	300 h.p. Minimum.	600 h.p. Preferred.	Minimum.	Preferred.	Minimum.	Preferred.	Minimum.	Preferred.
Horizontal water tube		10′	12′	10′	12′	8′	10′	8′	11′	8′	10′	10′	12′	12′	14′
Inclined water tube	Stirling type	7′	8′	6′	8′	6′	8′	5′	7′	6′	8′	6′	8′	7′	8′
	Bigelow-Hornsby	5′	6′	5′	6′	3′ 6″	5′	3′ 6″	5′	3′ 6″	5′	3′ 6″	5′	6′	8′
Vertical water tube	Erie City, Ladd, Rust	3′	4′	3′	4′	3′	4′	3′	4′	3′	4′	3′	4′	3′	4′
	Wiekes— 150 h.p.	4′ 6″	5′	4′ 6″	5′	4′ 6″	5′	3′ 3″	..	3′ 6″	4′ 6″	4′ 1″	4′ 7″	5′	5′ 6″
	250 h.p.	5′ 6″	6′	5′ 6″	6′	5′ 6″	6′	3′ 3″	..	3′ 6″	4′ 6″	4′ 1″	4′ 7″	5′	5′ 6″
	500 h.p.	6′	6′ 6″	6′	6′	6′	6′ 6″	3′ 3″	..	3′ 6″	4′ 6″	4′ 1″	4′ 7″	6′	6′ 6″
H.R.T. fire tube	150 to 175 h.p. 72″ diam.	8′	10′	8′	10′	7′	10′	7′	8′	6′	8′	7′	8′	8′	10′
	250 h.p. 84″ diam.	8′	10′	8′	10′	7′	10′	8′	9′	6′	8′	7′	8′	8′	10′

intelligent stokers. These can be obtained, if the price is paid, but such price is supposed to be prohibitory, for which reason mechanical aids have been introduced, yet even these require skilled operators, if the best economy is to be obtained, because whatever the excellence of mechanical methods may be, none have been produced that can compare with the best hand firing, both for fuel economy and quantitative efficiency."

No hand fired furnace has yet been devised which is independent of, or which by any feature in its design can compensate for lack of skill upon the part of the fireman. On the contrary, it may be observed that the better the furnace is designed, and the greater its potential efficiency and economy, the more important it is to provide skilled operation.

The ordinary hand fired natural draught furnace as usually supplied by makers of Lancashire and Cornish boilers as the standard firing equipment, while being unsuitable for the efficient burning of the higher grade fuels, is utterly useless for burning low grade fuels. As a standardised furnace it is designed and supplied without any regard for draught conditions, the grade of fuel which it is desired to use, or the evaporative duty required from the boiler.

The length of the grate, its design, and air spacing would appear to be points which have received little or no consideration. The usual practice has been to provide grates 6 ft. long and to use a standard air spacing, irrespective of individual conditions and requirements.

Owing to their limited range of use, their lack of flexibility, and their inefficiency, to a very large extent these furnaces have been superseded by furnaces capable of burning a wide range of fuels and a limited range of low grade fuels.

While for natural draught operation many improved firebars have been introduced, to a considerable extent the tendency in hand firing has been towards the adoption of furnaces suitable for burning slacks and small fuels, and also for enabling an evaporative output to be obtained from boilers in excess of that obtainable under natural draught.

For these purposes forced draught or steam jet blower furnaces have been very extensively adopted. Furnaces of this type were originally introduced upwards of thirty years since for the utilisation of coke breeze for steam generation in gas-works, at a time when coke breeze was a waste fuel. The results then obtained were so satisfactory that similar furnaces embodying various improvements were widely adopted, not only for the utilisation of small and inferior fuels, but also for overcoming defective natural draught, and increasing the evaporative capacity of boilers when burning higher grade fuels.

Steam jet blower furnaces have already been referred to and illustrated in Chapter V. in connection with the utilisation of coke breeze for steam generation. The steam consumption of the nozzles or jets has been the subject of much criticism and controversy, and there can be no doubt that in connection with some furnaces of crude design the consumption of steam is excessive.

It has been customary to express the steam consumption in percentage terms

of the total evaporation of the boiler, sometimes without any regard for the class of fuel burned and accordingly the rate of evaporation obtained. It will be obvious that the percentage of steam used when burning a low grade fuel at a high rate of combustion, and giving a comparatively low evaporative output, must be much in excess of that required when burning a good quality of fuel at a lower rate of combustion, and giving a greater evaporative output.

Assuming a Lancashire boiler 30 ft. long × 8 ft. diameter burning coke breeze at the rate of 25 lbs. per square foot of grate, and giving an evaporation of 5000 lbs. per hour. The steam consumption should not exceed 3 per cent., or 150 lbs. of steam per hour. This cannot be regarded as excessive, and it may be observed that equivalent results in evaporation could not be obtained with any other system of air supply for a lower steam consumption.

For installations comprising three or more boilers in use at a time it would probably be more economical to use fan draught, either forced or induced, according to the conditions and requirements. Fine slacks, colliery smalls, and a limited range of low grade fuels may be efficiently utilised either with fan forced draught, induced draught, or both. The range of fuels which may thus be utilised is, as observed in Chapter II., to a large extent determined by the type of boiler used, and accordingly the grate area and combustion conditions provided.

Fan forced draught is only used to a very limited extent in connection with Lancashire and other internally fired boilers. Induced draught is much more widely used, and has given very satisfactory results, not only in overcoming defective chimney draught, but also in considerably increasing the evaporative output of boilers, and in enabling certain low grade and small fuels to be utilised.

Hand Firing.—The methods usually employed for hand firing more or less completely and satisfactorily—depending both upon the skill of the fireman and the degree of efficiency or supervision—may be briefly described as follows :—

(1) Side or alternate firing.
(2) Spreading.
(3) Coking.

Methods 1 and 2 are, as a general rule, only satisfactorily used by competent and experienced firemen, demanding, as they do, close attention, judgment and dexterity. Method 3 is unfortunately to a large extent used by the unskilled.

Whichever system may be adopted, it is imperative *to cover the grate and keep it covered.* In hand firing under any system or method this is essential, and cannot be disregarded, if there is to be any concern for efficiency in operation.

Some firemen never cover the grate, others fail to the extent of not keeping the grate adequately covered, and it is an all too common experience to find the rear of the grate bare or thinly covered, as also the sides, with holes in the fire.

Hand firing as practised by the untrained and unskilled is notoriously inefficient, and is productive of a grievous fuel waste ; it must, however, be admitted that the fault does not lie entirely with the operator. In many boiler houses a

fireman has to work in such a cramped position, with coal so close to the boiler front, that even a skilled man cannot satisfactorily fire a boiler under such conditions.

Generally speaking a clear firing space of at least 7 ft. is essential in front of a Lancashire boiler for efficient hand firing, and at least 10 ft. is required for smartly cleaning a fire. Failure to provide suitable working space involves constant loss.

The length of the grate provided, and the importance of correct grate area—which will be subsequently discussed—have a marked effect upon the results obtained.

In connection with many steam boiler installations the grates provided are too long. By reducing the length of the grate the work of the fireman, skilled or unskilled, is not only reduced, but is at the same time automatically rendered more efficient. The loss due to failure to keep the grate covered may in many cases

Fig. 135.—Contour of Fuel Bed, Side Firing.

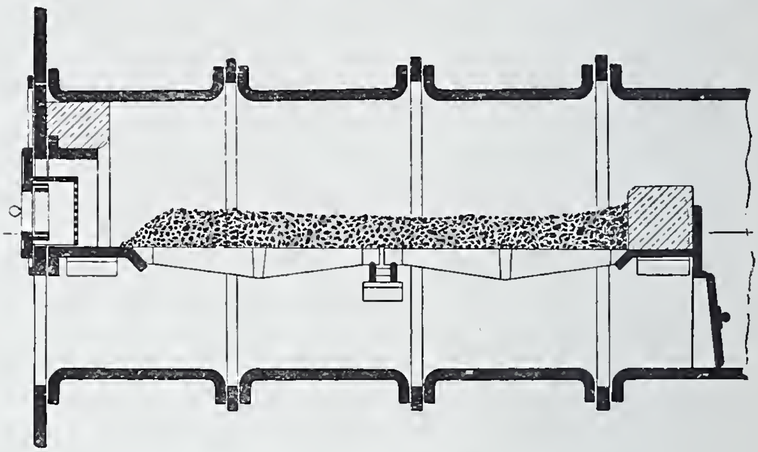


Fig. 136.—Contour of Fuel Bed, Side Firing.

be either considerably minimised, or even eliminated, by providing a grate area suitable for the evaporative duty demanded, having in mind the available draught and the fuel which it is desired to use.

Apart from the comparative advantages of the recognised methods of firing, it will be evident that the conditions provided both in regard to firing space and grate areas are not unimportant factors. The fireman cannot be held responsible for the design of the boiler house, nor the determination of the correct grate area.

(1) *Side or Alternate Firing.*—The firing of alternate charges on the right and left sides of the grate, sometimes known as wing firing, is a method commonly employed, demands skill in the "placing" of the fuel in order to keep the sides of the grate sealed, and also to keep the centre of the fire covered from front to back.

The charges must be small and frequent in order to maintain a hot fire. The thickness of the fuel bed should be from 7 in. to 9 in., according to the evaporative duty demanded and assuming the use of bituminous slack.

This method of firing to some extent combines the two systems which will be subsequently discussed, *i.e.* spreading and coking. It is not the most suitable method in cases where heavy duty is demanded, although in cases where a boiler is

working rather below its rated capacity it is probably the best and most efficient system of hand firing.

The contour of the fuel bed under good side firing conditions is shown in Figs. 135 and 136. With the spreading system, the fire should be equally level, care being taken to rather increase the fire thickness at the sides and rear end.

(2) *Spreading.*—For heavier boiler duty, and for the most efficient firing of fine bituminous slack, the spreading of the fuel from front to back is the best system.

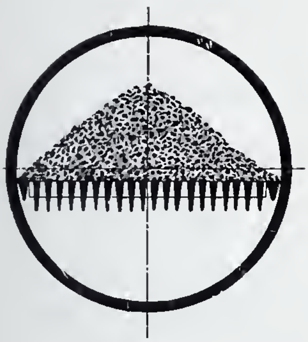


Fig. 137.—The Coking System.

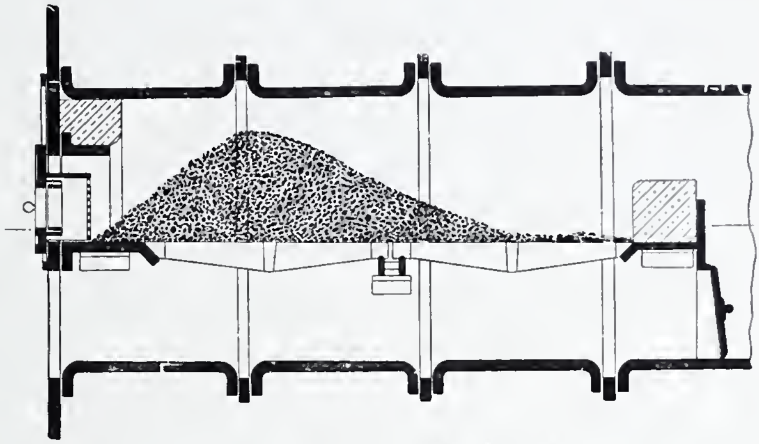


Fig. 138.—The Coking System.

In the United States a variation of the spreading system, known as "ribbon firing," has been introduced, light charges being fed in narrow rows from front to back.

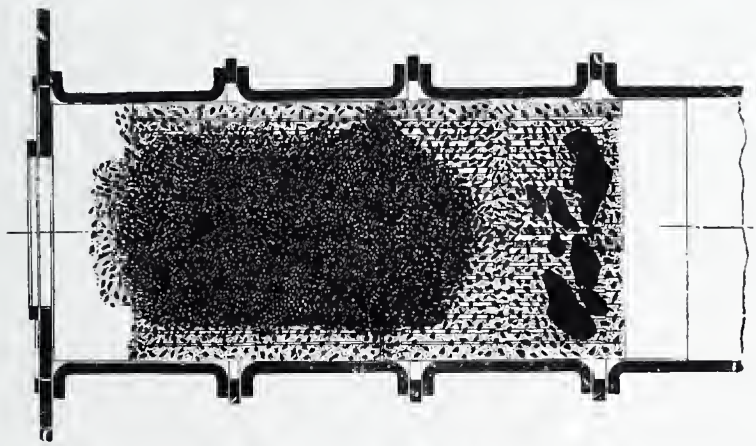


Fig. 139.—The Coking System, Plan.

While it has been shown that this method is superior to spreading as ordinarily practised, it can only be employed with grates of suitable width, such as are provided with externally fired boilers.

The essentials of the spreading system are to uniformly spread or sprinkle the fuel, and to maintain a level fire of even thickness and free from holes. To do this while meeting a heavy and fluctuating demand for steam necessitates close and intelligent observation of the condition of the fire, skill in the "placing" of

the fuel, hard work, and constant attention. The spreading system is not suitable for light boiler duty nor easy working conditions.

Coking.—For a steady load and comparatively easy working conditions the coking system of firing, *if satisfactorily done,* will show a very good efficiency and a freedom from smoke, even if no special smoke-preventing device is employed. This system of firing, however, is impossible for meeting a fluctuating demand for steam, it is also unsuitable for a heavy evaporative duty, unless artificial draught is provided. With the high rate of combustion it then demands very close attention in order to keep the grate adequately covered.

As a method of firing it is ancient, originally introduced as a means of preventing smoke, it is too often employed by unskilled firemen as an easy method of firing, involving but the minimum of effort, but, as frequently practised, disastrous from the point of view of efficiency.

The object of the coking system of firing is to coke the fuel at the front of the grate, always maintaining a level incandescent fire at the rear, to ignite the gases distilled at the front. The method, which is much too frequently adopted, is illustrated in Figs. 137, 138 and 139. A mass of fuel is dumped at the front of the grate, while the rear portion of the grate is either left bare or imperfectly covered.

Unless it can be ensured that the whole of the grates at the rear is kept evenly covered to a depth of at least 6 in., by systematically and regularly levelling the coking mass, this method of firing should not be permitted. In effect this means that as a system its use should be restricted either to skilled firemen or those who are working under proper supervision.

To permit this method of firing to be practised without any regard for the adequate covering of the grate is to encourage and ensure inefficiency and waste, whereas if properly applied it is not only an easy method of firing, but under suitable conditions, and within its limitations, will ensure smokeless and efficient operation.

Raking and Slicing.—So long as a fire is kept sufficiently thick and level it is unnecessary to disturb it by raking, poking, or slicing. The use of the slice should at all times be restricted to gently easing the underside of the fire in order to free the air spaces and riddle through loose incombustible dust to the ashpit.

This, unfortunately, is the method which is only employed by the skilled firemen. Untrained men seem to be obsessed with the idea that a fire requires constant manipulation and disturbance.

It cannot be too strongly emphasised that the rake should only be used to level the fire and remove clinker and ash. Instead of this it is an all too common practice to break up the fire indiscriminately, mixing ash and clinker with partially burned and unignited coal. In the same way the slice is thrust into the body of the fuel bed which is partially turned over, mixing clinker and ash with burning coal.

When artificial draught is used, or in cases where the chimney draught is sharp, one effect of thus unnecessarily breaking up the fire is to liberate small particles of

partially carbonised gritty fuel, which in large quantities is carried forward to the flues and chimney.

Cleaning Fires.—The carbon loss in cleaning fires due to lack of skill, carelessness, indifference and lack of supervision is serious, and represents a heavy waste, the extent of which in connection with hand fired furnaces has not yet been fully realised.

Not only is the loss of carbon in the residual clinker and ash frequently very heavy, but the loss in riddling with ordinary natural draught furnaces is by no means negligible. To these losses have to be added the waste due to excess of air passing over and through the grate, and the distillation of the hydrocarbons under conditions which prevent ignition. These all contribute to a heavy fuel loss which is to a large extent preventible.

A fire should always be cleaned before it has burned too low, and for at least fifteen minutes before cleaning the firing should be strictly limited.

Under average conditions the thickness of the bed of fire on a grate at the time for cleaning should not exceed from 3 to 4 in. In order to quickly and thoroughly clean a fire, and rapidly regain normal working conditions, activity is demanded, and preferably skill; leisurely methods are very wasteful.

The fire should be smartly pushed over to one side of the grate, leaving the opposite side bare. Directly this is done all unburned fuel should be quickly raked over on to the bare grate surface, leaving only the clinker and ash, which should be at once removed. Immediately the grate has been cleaned the live fuel should be spread, and small and frequent charges introduced, until a level fire of the required thickness has been reached and the normal working temperature secured.

Heavy charges should not be introduced, the essential point after cleaning is to regain a high furnace temperature with the minimum loss of time.

It is important when cleaning fires to lower the dampers in order to restrict so far as is possible the inrush of cold air. Unless this is done the unchecked flow of air must inevitably cool the furnace and boiler and result in a definite loss.

Although in most boiler installations the damper counterweights are so placed that the dampers may be readily manipulated, it is only the skilled and careful fireman who realises the importance of regulation or adjustment.

In the utilisation of low grade fuels for steam generation under hand fired conditions, the cleaning of fires as ordinarily practised is both arduous and wasteful. Not only is it necessary to clear the fires much more frequently, but the proportion of incombustible which has to be removed is often considerable.

In order to avoid the usual burning down process and facilitate cleaning, a simple form of baffle bridge (Gallagher & Crompton's patent) has been introduced. This device, which is in the form of an inclined extension of the grate in firebrick, is illustrated in Figs. 140 and 141, the former showing the normal condition of the fire and the latter the condition of the fire when cleaning out. The live fuel is pushed back on to the bridge instead of being burned down; not only does this provide a larger body of fire for covering the grate immediately after clinkering,

but during the removal of the incombustible from the grate the mass of live fuel on the bridge restricts the area over the bridge and accordingly limits the inflow of air.

Having in mind that the baffle bridge in effect increases the grate area, it would appear to be most useful when comparatively short grates are used. To add from 2 ft. 6 in. to 3 ft. to a standard 6 ft. grate, plus the usual dead-plate,

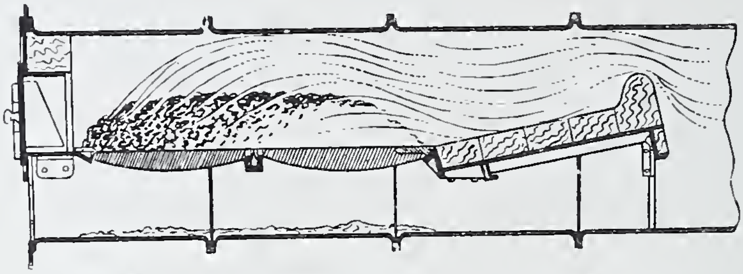


FIG. 140.—GALLAGHER & CROMPTON'S BAFFLE BRIDGE. NORMAL CONDITION.

must obviously increase the work involved in the manipulation of the fire, as the live fuel has to be handled with the rake twice at a distance of 9 ft. to 10 ft. from the front of the boiler.

The Importance of Correct Grate Area.—Generally speaking the grate or grates installed in hand fired boilers are too long. As already observed, it would appear to be the common practice for makers of internally fired boilers, such as those of

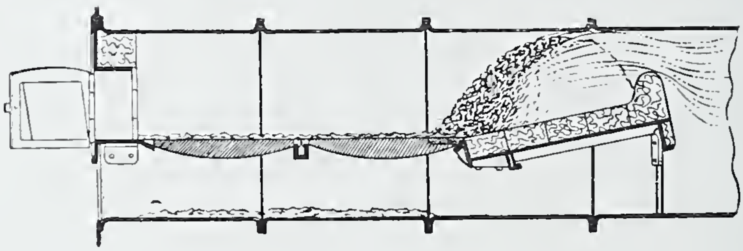


FIG. 141.—GALLAGHER & CROMPTON'S BAFFLE BRIDGE, IN USE FOR CLEANING FIRE.

the Lancashire and Cornish types, to provide grates at least 6 ft. in length, without any regard for the evaporative duty actually required from the boiler, the class or character of the fuel to be utilised, or the conditions under which the boiler has to work.

Further, the question of suitable air spacing would seem to receive no consideration : a grate of standard length with standard air spacing is provided, no matter what kind of fuel it is intended to use, and without any regard for the existing chimney conditions.

Having in mind that it is the usual practice to fix a 9-in. or 12-in. dead-plate in front of the grate, the fireman, in order to keep the grate evenly covered, has to throw the fuel over 7 ft., and in this operation place it where it is wanted.

It is quite useless to ignore the fact that as a general rule this is not done. The average fireman either will not, or does not, cover a grate 6 ft. long, and it is commonly found that the back of the grate, for from 12 in. to 18 in. at the bridge, is either bare, or thinly and unevenly covered with fuel.

If under such conditions it is possible to maintain the required steam pressure and boiler output, although inefficiently, then it is beyond question that with a shorter grate evenly covered with fuel the consumption would be reduced,—in many cases substantially,—and the steam required would be obtained with much less effort.

To a large extent steam users have relied upon boiler makers, and it is to be regretted that the latter do not appear to be seriously concerned with thermal efficiency in practice, nor do they show that to any serious extent they appreciate ordinary problems in combustion, and the fact that the performance and efficiency of the boiler is to a large extent dependent upon the furnace or firing equipment.

The simplest and cheapest method of reducing the grate area is to cover the back end of the grate with firebricks or firetiles for one or two feet in length from the bridge, or even more, as may be easily determined by experiment.

The effect is to intensify combustion, ensure a higher furnace temperature, and increase the absorption of radiant heat, due to the comparative ease with which the grate can be kept evenly covered with fuel. Further, the fire can be more easily, quickly, and thoroughly cleaned.

Cases have come under the observation of the author where with grates 6 ft. in length, the average rate of combustion was only 7 lbs. per square foot of grate per hour. In two such cases the only complaint made was that the superheat or added steam temperature was much too low, being actually about 50° F. only.

The obvious remedy was to shorten the grates and these were reduced by one-half, *i.e.* from 6 ft. to 3 ft. in length, when by reason of the intensified combustion, the increased furnace temperature, and accordingly the higher downtake temperature, the required increase in superheat was obtained, effecting a material reduction in the fuel consumption.

When it is borne in mind that grates 6 ft. long are almost invariably found to be imperfectly covered, even when fuel is being burned at the rate of from 15 lbs. to 25 lbs. per square foot. of grate per hour, it is very difficult to understand how any one can reasonably expect to keep a grate of equal area covered when only burning at the rate of 7 lbs. per square foot of grate per hour.

While excessive grate area is an all too common fault with hand fired boilers, it must not be assumed that in this important respect mechanical stokers are perfect.

In some cases mechanical stokers as applied to Lancashire boilers are provided with grates much too long with a view to ensuring the complete combustion of the fuel before it leaves the grate.

Even if this is accomplished, which is not always the case, because it depends upon the fuel and various other factors, the grate at a point about 5 ft. from the front will very often be found to be very thinly covered with fuel, ash, or clinker.

In some cases the grate at this point and beyond is bare. Almost invariably

with long grates the excess of air passing through at the back end is very heavy and is directly responsible for a very heavy loss in efficiency and a serious waste of fuel.

The shortening of grates offers to the steam user a simple and ready means of effecting a substantial reduction in fuel consumption in a very considerable number of cases, and this with the minimum of trouble and expense.

The Loss due to Excess of Air.—The loss due to excess air is one of the most serious, if not the most serious, of all losses in steam boiler operation. It has already been referred to, but its importance is such that it is felt desirable to summarise the contributory causes of excess air admission thus :—

Furnace losses due to :—

(*a*) Grates of excessive length.
(*b*) Grates not uniformly or evenly covered with fuel.
(*c*) Fires too thin.
(*d*) Holes in the fires.
(*e*) The use of coal too large in size to permit of properly covering the air interstices. Coal should be broken down to from 3 to 4 in. cube.
(*f*) Slicing fires too frequently.
(*g*) Unnecessary raking of fires.
(*h*) Carelessness in cleaning fires.
(*i*) Failure to use dampers to regulate the draught.
(*j*) Firing through two doors in rapid succession instead of alternately at intervals.
(*k*) Badly fitting or warped furnace fronts and fire doors.
(*l*) Excessive draught.
(*m*) Failure to regulate the draught or air supply to the size of the fuel and the thickness of the fire.
(*n*) Cracks in furnace brickwork.
(*o*) Cracks or crevices at metal joints in brickwork.
(*p*) Badly fitting cleaning out or access doors.

Boiler losses due to :—

(*a*) Cracks in the brickwork setting due to expansion and contraction.
(*b*) Crevices at metal joints in brickwork.
(*c*) Openings between boiler shell, or drums, and brickwork.
(*d*) Badly fitting dampers.
(*e*) Badly fitting cleaning out or access doors.

Trivial or unimportant as some of the individual causes may appear, they are nevertheless responsible in the aggregate for an enormous and unnecessary waste of fuel.

In all cases where the thermal efficiency obtained is low, investigation will show that this is usually not due to any single cause, but to a combination of

causes, and in many cases the most serious causes of waste and inefficiency can be remedied with but a trifling expenditure and the minimum of trouble.

Combustion Space.—High volatile fuels are extensively used for the generation of steam under unsuitable conditions. Fuels of this kind demand for their efficient use considerably more combustion space than has yet been generally realised.

With water tube boilers it is possible to so set the boiler that any high volatile fuel can be efficiently utilised. The present tendency is to provide a far larger combustion space than hitherto, and in connection with many modern installations it is evident that the improved setting does substantially increase the efficiency obtained.

With internally fired boilers, such as those of the Lancashire and Cornish types, the combustion space can only be increased within very small limits by lowering the grate level.

If, as is shown with water tube boilers, the increased combustion space is necessary in order to obtain the highest efficiency with high volatile fuels, then it must necessarily follow that an internally fired boiler with but a limited combustion space does not present the most suitable conditions for burning similar fuels.

This suggests the desirability of using for internally fired boilers fuels with a lower volatile content, and it is for this reason that Lancashire boilers, fired with bituminous coal having from 10 to 20 per cent. of volatile content, Welsh steam coal, and coke, usually show a higher efficiency than when a high volatile fuel is used.

The conditions presented in the limited combustion space provided with Lancashire and Cornish boilers cannot be said to be suitable for the efficient combustion of the highest volatile fuels, and the more general recognition of this will be a definite step towards the avoidance of waste, and the prevention of smoke.

CHAPTER XIII

STEAM BOILER AND BOILER HOUSE EQUIPMENT

In the two previous chapters steam boilers have been discussed, as also their equipment for the efficient burning of low grade and waste fuels. In this chapter it is proposed to discuss boiler and boiler house accessories, having for their object the promotion of efficiency and economy in the use of furnaces and fuel for steam generation, as also apparatus for determining the sources of waste and loss and their extent.

While much depends upon the provision of suitable accessories, it is scarcely necessary to observe that much more depends upon their intelligent operation. It is possible to spend a considerable amount of money upon such equipment, without securing a return in increased efficiency in any way commensurate with the expenditure.

Without suitable apparatus it is useless to look for anything but irregular and spasmodic efficiency at the best. With suitable apparatus it is equally useless to look for efficient results, unless the apparatus installed is understood and operated with care.

Efficiency in operation does not entirely depend upon the provision of suitable accessories and their use, but rather upon the close study and application of the lessons taught, the deductions to be made, as also upon the keeping of constant records.

In an excellent handbook, entitled "Boiler Inspection and Maintenance,"[1] by Mr R. Clayton, boiler house operation is thus referred to :—

"Whilst carelessness and incapacity amongst plant attendants is not uncommon, the boiler owner himself must be indicted of being largely responsible for the neglect of boiler house plant—neglect which unfortunately is much in evidence. Boiler owners as managers of their own power plants seem too prone to regard their boiler house as a 'non-productive department,' which must be tolerated as a necessary evil ; whereas the more correct attitude is surely to consider it as a factory in itself, wherein the raw materials are air, coal, and water, and the finished product is steam of a given quality.

"It is a singular fact that whilst he will often strive after the last quarter of a pound of steam per horse-power in his engine room, the boiler owner has but the haziest notion, say, of the calorific value of the fuel which he buys and burns in hundreds or thousands of tons per annum.

"In like manner, whilst he is able to appreciate the capitalised value of such

[1] "Boiler Inspection and Maintenance," by R. Clayton, 1921.

renewals and repairs as are effected, he is not always able to appreciate that the latter might very likely be halved or even decimated, by quite a moderate amount of thorough and systematic attention to supervision."

Broadly speaking, there are only two ways in which the avoidable waste of coal can be stopped. Consumers must either be compelled to burn coal efficiently, or be educated up to it. Compulsion or control in industrial operation is most undesirable.

The only logical alternative is to so educate the steam user that he is able to realise that as ordinarily practised, the burning of coal is inefficient, wasteful. and unnecessarily expensive, unless under expert guidance or control.

The scientific control of boiler house operation, and the provision of suitable equipment, has been advocated for many years past by engineers who have realised the enormous scope for economy, but as already observed in a previous chapter, we are still face to face with avoidable waste to an extent which is almost incredible.

Some boiler accessories, such as mechanical stokers, have already been discussed, it is therefore unnecessary to further discuss the same at any length. This to a large extent applies to firing equipment generally. The main point to be emphasised here, is that the efficient performance of a steam boiler is to a large extent determined by the suitability and efficiency of the firing equipment provided, and the degree of efficiency in its operation.

With skilled operation it is possible to obtain a very fair ultimate efficiency with a comparatively poor furnace equipment and a low grade fuel. On the other hand it is equally possible with unskilled or indifferent operation and lack of control, to obtain a very low efficiency, even with the most suitable and efficient apparatus and the best fuel. It is useless to ignore the fact that accessories and apparatus of the highest class are but the *means* of obtaining and maintaining efficiency. Without intelligent operation, without continuous and systematic application. without close and skilled supervision, control, and management, it is not possible to maintain high thermal efficiency. Therefore ultimate efficiency

$$= E \times H$$

where E = equipment, and
H = human element.

In the United States it has been said that "it is one thing to stop waste, but it is another thing to keep waste stopped." There is an obvious truth in this. Spasmodic effort means at the best spasmodic efficiency, and avoidable waste will not be eliminated by this method.

The Raw Materials.—The raw materials to be dealt with are air, coal, and water. The whole of the equipment required is necessary to so handle and control these at all stages in their use and condition, that the finished product—steam—is obtained continuously at the lowest possible coat.

Air Supply.—Among the most important of all accessories is means for obtaining the necessary air supply. Whether chimney or natural draught is used or alternatively forced, induced, or suction draught, is mainly a matter of choice,

circumstances, or conditions. The important points are that the draught or air supply must be adequate and efficient.

The ideal draught is that which permits of the maintenance of a constant relation between the weight of fuel used, and that of the air supplied, under all combustion conditions. Judged by this standard the ordinary chimney is a complete failure.

There is no more wasteful and inefficient system of air supply than so-called natural or chimney draught, of which it may be said, the greater the waste the better the draught. In other words, the higher the temperature of the gases entering the chimney the sharper the draught.

While it must be admitted that a well-built chimney has a long life and a low maintenance cost, while also possessing the merit of simplicity, yet chimney troubles are not infrequent, although usually traceable to very simple causes, some of which it may be worth while to enumerate :—

(1) A deficiency of draught is frequently caused by connecting up an additional boiler, or boilers, to a chimney originally designed for the boilers first installed, and having insufficient sectional area for additional boilers.

(2) Baffling due to the connecting up of flues to a chimney in such a manner that the gases from two or more flues are not divided at the chimney base by means of a mid-feather wall.

(3) Flues of insufficient sectional area.

(4) Water or dampness in the flues.

(5) Sharp bends or sudden changes of sectional area in the flues.

(6) The installation of economisers.

(7) Air infiltration, due to faulty brickwork, or badly fitting doors, with a consequent dilution and cooling of the gases.

(8) The building of fire bridges too high.

It is frequently found that the condition of brickwork settings is responsible for a serious reduction in the draught, as the result of air infiltration through cracks and openings due to expansion at points where frames and doors are built into the setting, and also at the dampers.

Periodical examination of the brickwork externally is necessary, and all cracks and openings should be carefully and thoroughly closed. The effect upon the draught and the fall in efficiency due to air infiltration are out of all proportion to the little trouble and expense involved in ensuring tight brickwork.

It is desirable to examine the brickwork setting internally, with a view to ascertaining if there is any short circuiting of the gases. Air leakage between the front cross wall and the boiler shell is frequently found. Short circuiting of the gases at the downtake is also commonly found with Lancashire and Cornish boilers, where cracks develop in the back wall and also at the side walls of the setting.

With water tube boilers the condition of the brickwork setting, as also the internal baffles, have a marked effect upon the working efficiency. External brickwork faults may be remedied in precisely the same manner as already referred to. Leakages through baffles, sometimes due to movement, breakage, or a baffle having fallen

out of position, can only be detected by complete examination. In connection with large water tube boilers there is now an increasing tendency to use insulated steel plate casing, which renders unnecessary all brickwork with the exception of the refractory lining. This method of setting is very efficient, and to a large extent prevents the losses already referred to in connection with brickwork setting.

It will be obvious that in any serious attempt to secure the highest thermal efficiency it is important to discharge the products of combustion from the chimney at the lowest temperature practicable, *i.e.* to utilise the maximum percentage of the heat units in the gases. That this is not possible under chimney draught conditions is beyond question. It is clearly recognised that the term " chimney loss " is only another way of indefinitely stating the price which has to be paid for providing the draught.

Under ordinary or average conditions the chimney loss may be from 16 per cent. to 25 per cent., or even more under bad conditions, and when other heat losses have been reduced to the lowest possible level, a constant loss at the chimney has still to be faced.

The following Table, No. 39, will be of interest as showing the various heat losses under good average operating conditions. It will be observed that in this case no less than 52 per cent. of the total loss is represented by the chimney loss.

TABLE No. 39

(1) *Losses greatly affected by Operation*

	Percentage of total heat of fuel.	Percentage of total loss.
(*a*) Loss due to heat carried away in the flue gases	16·37 per cent.	52 per cent.
(*b*) Loss due to unburned CO	1·78 ,,	5·8 ,,
(*c*) Loss due to unconsumed carbon in ash .	4·75 ,,	15·1 ,,
	22·90 ,,	72·9 ,,

(2) *Losses not primarily due to Operation*

(*d*) Loss due to moisture in coal . . .	0·35 per cent.	1·1 per cent.
(*e*) Loss due to moisture formed in burning the coal	3·26 ,,	10·4 ,,
(*f*) Losses due to radiation and unaccounted for	4·91 ,,	15·6 ,,
	31·42 ,,	100·00 ,,

While the foregoing table shows the losses under good average operating conditions, Fig. 142 shows the losses in the proportions which are more commonly found, and more particularly the chimney loss.

In Table No. 40 is shown the boiler efficiency with exit gases at temperatures from 300° to 750° Fahr., and CO_2 percentages from 15 to 5 per cent.

Induced or Suction Draught.—The most convincing evidence in favour of mechanical draught as compared with chimney draught is found in the fact that in generating stations, and also in other industries where the highest thermal efficiency is sought, the use of chimney draught has to a large extent been abandoned. In the installation of modern boiler units the almost invariable practice is to provide a complete mechanical draught plant, either for each individual boiler, or alternatively for each pair of boilers.

The saving effected is much in excess of the cost of operation of the draught plant, in addition to which a range in flexibility and control is provided which is

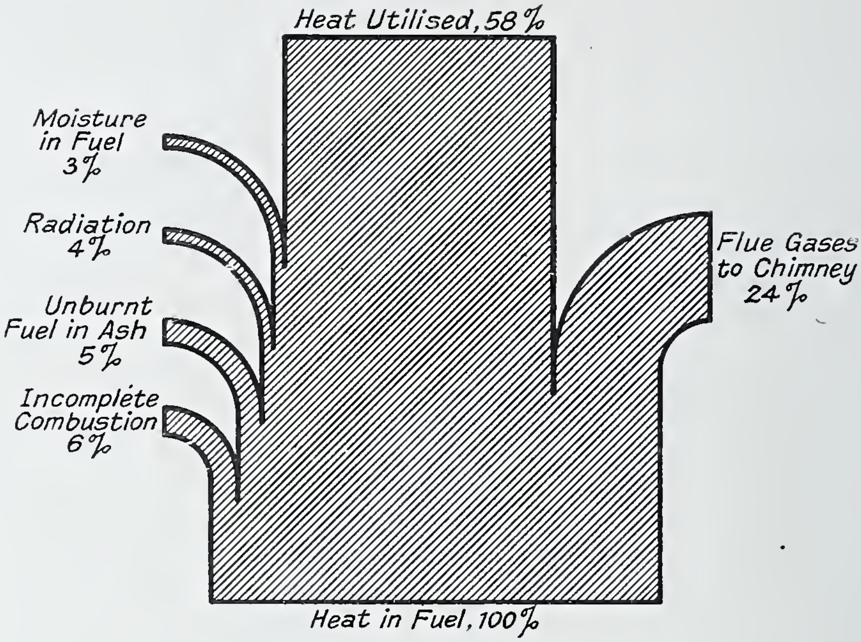


Fig. 142.—Graph showing Combustion Losses.

impossible with chimney draught. Thicker fires may be used, with the result that excess air is reduced, and as compared with chimney draught the operation of the plant is not adversely affected by external or atmospheric conditions. In Fig. 143 is shown the chimney loss with exit temperatures varying from 200° to 700° Fahr., and a CO_2 content varying from 5 to 15 per cent.

With induced draught the fan has not only to carry away to the chimney the whole of the products of combustion, but also to provide the whole of the air supply, maintaining a sufficient suction throughout the boiler and its connections to overcome the resistance of the grate and the fuel bed.

One defect of induced draught is in the constant liability to loss through air infiltration at all cracks and openings. While this is a defect with chimney draught, it is more serious with induced draught, and accordingly demands greater vigilance.

Apart from entirely new and complete installations, usually comprising in

addition to the draught plant a comparatively small steel chimney, induced draught has been extensively adopted in connection with existing chimneys for overcoming deficiency in draught, as also for the utilisation of low grade fuels.

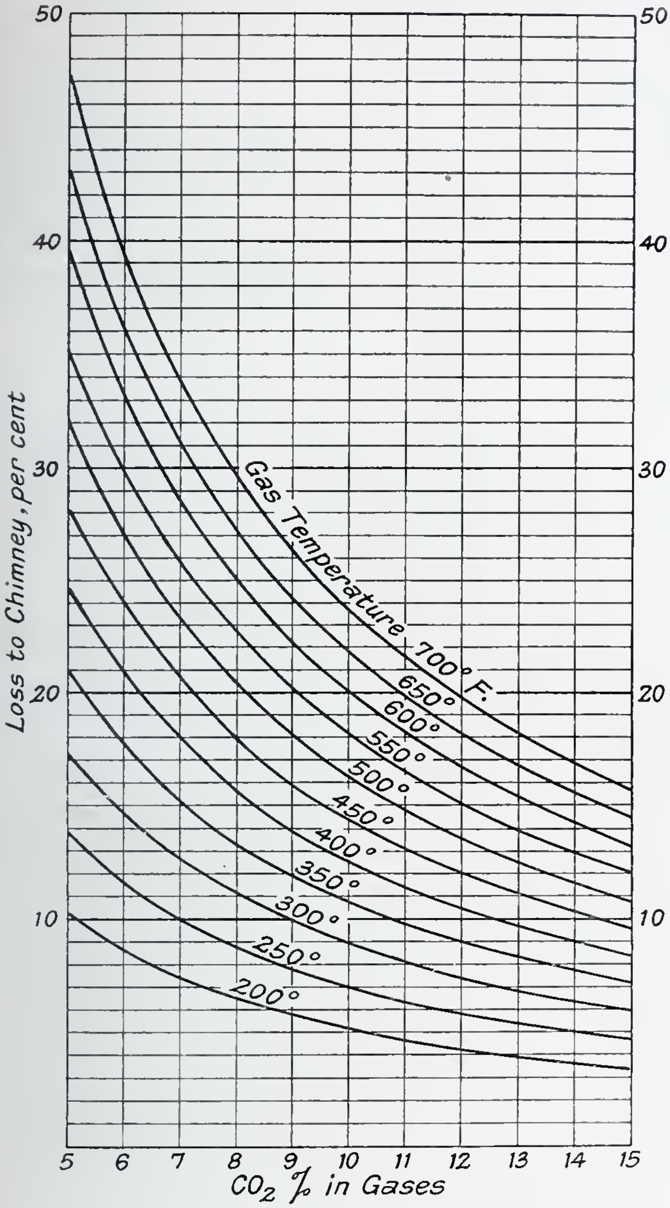


Fig. 143.—Diagram showing Chimney Loss, with varying Exit Temperature and Percentage of CO_2.

Forced Draught. — Forced draught apparatus may be divided into two distinct groups, the one comprising steam or motor driven fans, the other steam jet blower furnaces.

While with induced draught the ashpits are open, with forced draught they are closed, the air supply being delivered into the ashpits and forced through the fires.

In actual steam consumption it is usually more economical to use a fan than steam jet blowers, particularly is this the case in all installations where more than one boiler is used. In the low cost of the apparatus, in simplicity, reliability, and in furnace maintenance cost the forced draught furnace has the advantage.

Both types of forced draught have been extensively adopted for the utilisation of low grade fuels, and for overcoming defective chimney draught, but neither can be compared with induced or suction draught in efficiency because they do not displace chimney draught; ample draught capacity is still required to take away the products of combustion.

Balanced Draught.—In connection with many of the larger installations balanced draught is now used, comprising both induced and fan forced draught, operating in combination and under careful regulation and control.

Prat Induced Draught.—The important points of difference between Prat induced draught and other systems of direct suction draught (commonly termed induced draught) are as follows :—

With the latter system the whole of the hot gases pass through the fan, and travel thence to the chimney. This involves not only a larger fan than is required

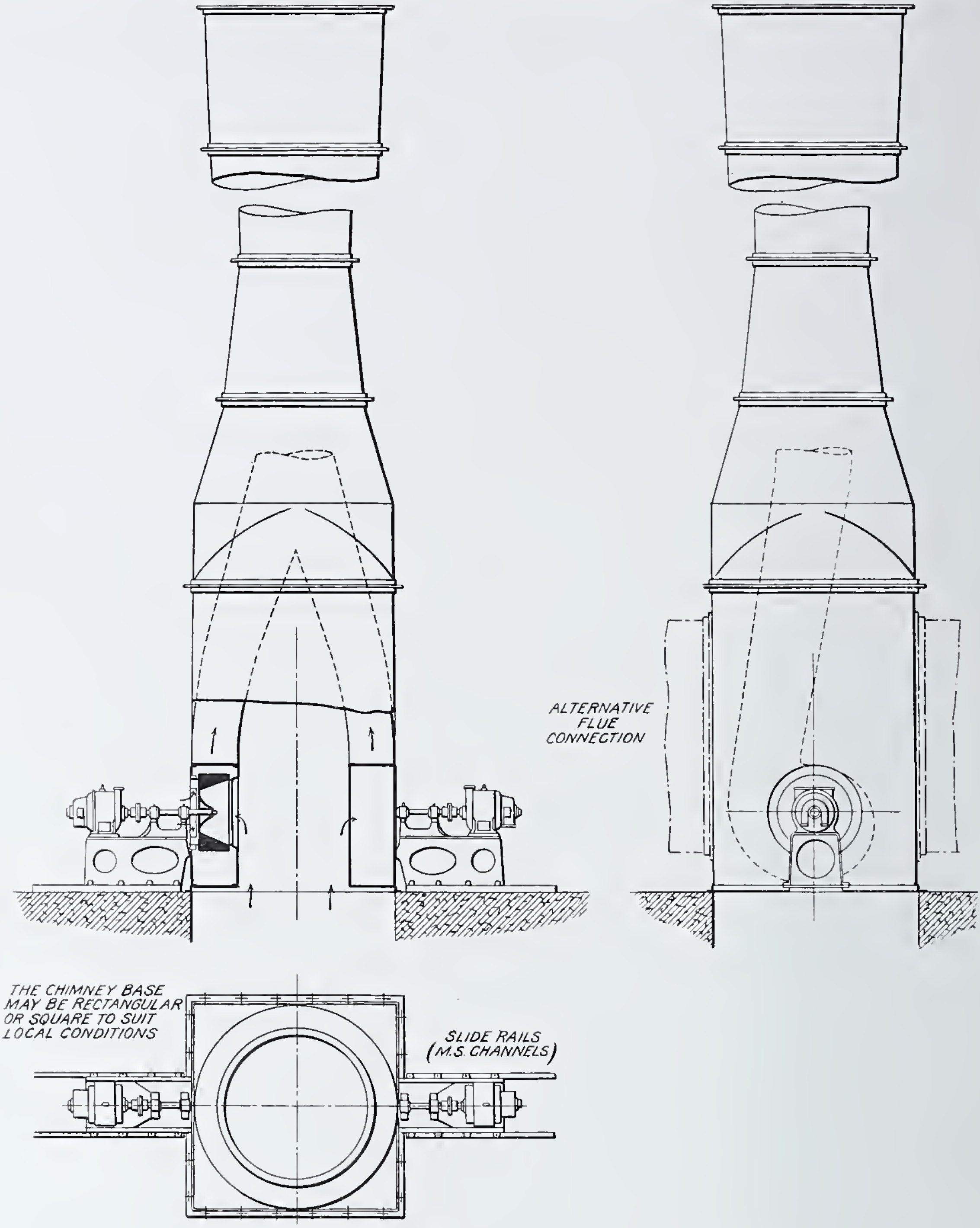


FIG. 144.—PRAT INDUCED DRAUGHT.

with the Prat system, but also considerably more power for driving the fan, in addition to which the benefit of the natural draught is lost.

As will be observed upon reference to the illustrations, Figs. 144 and 145, the

form of the chimney used with the Prat system is freely divergent, and as no damper is used the resistance of the circuit of the gases is practically unchanged; further, while the fan is in use the benefit of the natural draught is retained.

Only a small proportion of the total volume of hot gases pass through the fan, this small volume being used to accelerate the flow of the main volume of the gases.

The Heating of Air for Combustion.—The employment of heated air for com-

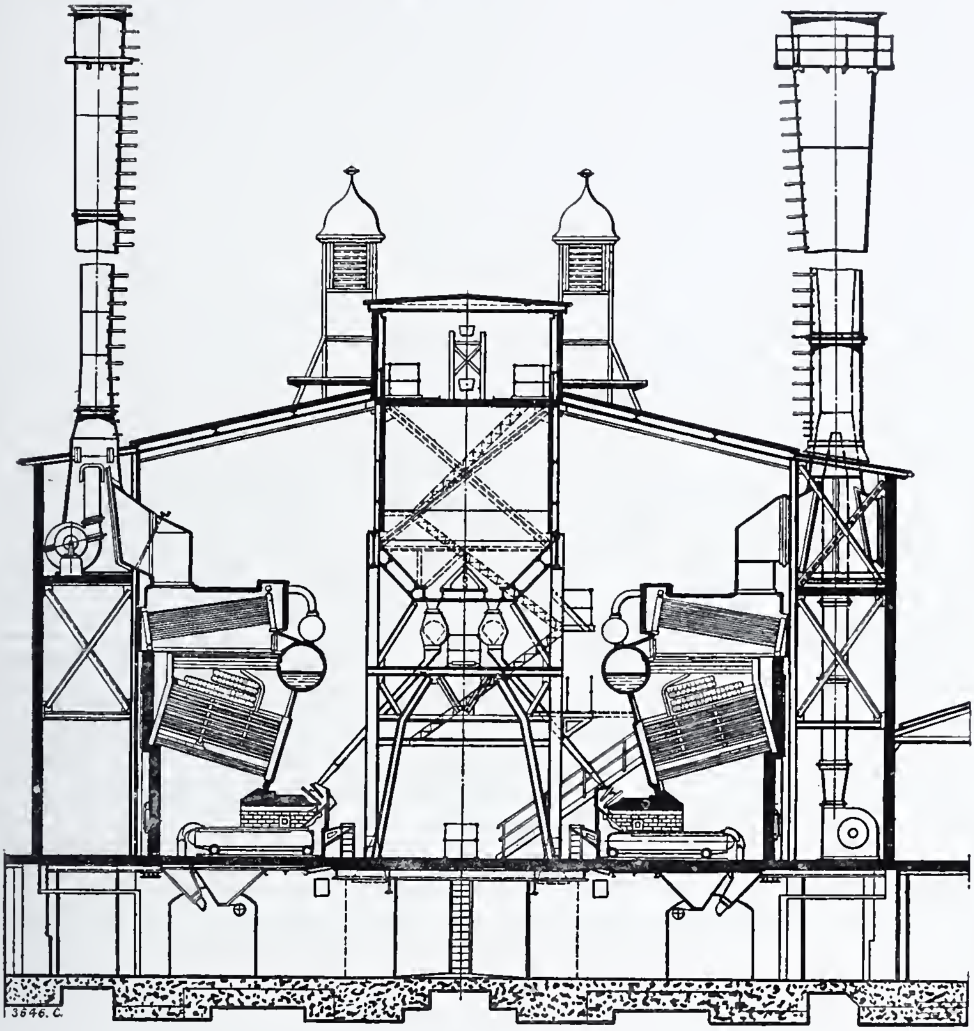


Fig. 145.—Cross Section through a Boiler House, showing Prat Draught.

bustion has been advocated for many years past, its advantages are such as to be beyond question, but it has yet to come into extensive use. For the utilisation of low grade and waste fuels the use of heated air for combustion is of much importance.

Any consideration of means for increasing the thermal efficiency of steam boilers would be incomplete without some reference to the utilisation of waste heat for pre-heating the air supply for combustion.

In 1881 and 1882 Mr J. C. Hoadley and Mr Fred. H. Prentiss carried out exhaustive tests in air heating at the Pacific Mills, Lawrence, Mass., U.S.A. Complete

details of these tests will be found in Volume 6 (1884–85) of the "Transactions of the American Society of Mechanical Engineers."

For these comparative tests three horizontal return tube boilers of the same size were used, two of which were provided with air heaters. The air heater for one boiler comprised 240 horizontal 2-in. tubes, each tube being placed inside a 3-in. sheet-iron tube, the latter being embedded in mortar.

TABLE No. 40

Boiler Efficiency with Exit Gases at Temperatures of from 300° F. to 750° F. and CO_2 percentage from 15 to 5 per cent.

Temperature of exit gases.	Percentage of CO_2 by volume.										
	15 per cent.	14 per cent.	13 per cent.	12 per cent.	11 per cent.	10 per cent.	9 per cent.	8 per cent.	7 per cent.	6 per cent.	5 per cent.
300° F.	80·25	79·9	79·5	79·0	78·5	78·0	77·0	76·0	74·75	73·0	70·0
350° ,,	79·0	78·7	78·25	77·75	77·0	76·0	75·0	74·0	72·25	70·0	67·0
400° ,,	78·0	77·5	76·75	76·0	75·25	74·25	73·0	71·75	70·0	67·5	63·5
450° ,,	76·75	76·0	75·5	74·75	73·75	72·5	71·0	69·5	67·5	64·5	60·25
500° ,,	75·5	74·75	74·0	73·25	72·0	70·75	69·5	67·75	65·0	62·0	57·0
550° ,,	74·25	73·5	72·75	71·75	70·5	69·0	67·75	65·5	62·75	59·0	53·75
600° ,,	73·0	72·25	71·25	70·25	69·0	67·5	65·75	63·25	60·0	56·0	50·25
650° ,,	71·9	71·0	70·0	69·0	67·5	65·75	63·75	61·0	58·0	53·5	47·0
700° ,,	70·7	69·75	68·75	67·5	66·0	63·75	62·0	59·0	55·5	50·75	44·0
750° ,,	69·5	68·75	67·5	66·0	64·0	62·0	60·0	57·0	53·0	48·0	41·0

The flue gases were passed through the 2-in. tubes, while the air supply for combustion was drawn through the annular space between the 2-in. and 3-in. tubes.

The second or alternative air heater was made up of 2-in. tubes for the passage of the gases, but outer tubes were not used. Instead sheet-iron baffles were so arranged as to guide the air supply across the external surfaces of the tubes several times.

Some average results obtained during these tests were as follows :—

	Boiler No. 1, without air heater.	Boiler No. 2, air heater with outside tubes.	Boiler No. 3, air heater with single tubes and baffles.
Temperature of external air, degrees F.	78	34	49
Temperature of air supplied to furnace, degrees F.	78	337	334
Temperature of gases leaving boiler, degrees F.	368	397	377
Temperature of gases leaving heater, degrees F.	..	189	164
Efficiency, corrected for differences in temperature of external air, per cent.	68·9	78·2	81·4
Percentage saved over operation without heater	..	11·9	15·4

Briefly summarised the advantages of using hot air for combustion may be stated as follows :—

(1) The utilisation of a large proportion of the heat units contained in the gases which otherwise would be discharged from the chimney.

(2) In facilitating the combustion of cheap, low grade, and high moisture fuels, also in considerably reducing the proportion of unconsumed carbon in the riddlings and ash.

(3) In increasing the combustion temperature, and accordingly the furnace and boiler efficiency.

The sensible heat represented in the chimney loss is given in the formula :—

$$P=0{\cdot}37\,\frac{T-t}{a}$$

in which

T=temperature of the gases in degrees F.
t=temperature of the surrounding atmosphere.
a=CO_2 by volume in the flue gases.

Fig. 143 shows graphically that the losses to the chimney vary directly as the temperature of the gases, and inversely as the percentage of CO_2 in the gases.

Hence it will be evident that to reduce this loss to the minimum the CO_2 content of the gases must be high, and the temperature of the gases must be reduced to the minimum practicable.

The heating of air by means of waste gases involves the use of mechanical draught, *i.e.* suction or induced draught ; this is necessary because of the reduction of the temperature of the gases passing through the air heater.

The advantages of using heated air are, as already observed, not confined to the obvious gain derived from the addition to the furnace temperature of the heat abstracted from the waste gases.

The use of hot air in the furnace improves the combustion by promoting chemical action, hot air giving a more rapid reaction and a higher furnace temperature. The effect upon the hydrocarbon gases is very marked. Further, with the use of hot air it is found that the excess air can be reduced, with a correspondingly higher percentage of CO_2 in the gases. The increase of furnace temperature may be said to correspond to the increase of the CO_2 content.

In the combustion of high moisture fuels the use of hot air is very advantageous. Many years since it was demonstrated in connection with refuse destructors that the use of a regenerator or recuperator for heating the air supply for combustion greatly improved the results obtained.

Towns' refuse may be regarded as a low grade and high moisture fuel, having in mind that the average composition is about one-third each of moisture, incombustible and combustible.

Experience has shown that, as a general rule, the decrease in the final gas temperature from a boiler is about 20 per cent. of the increase in the initial furnace temperature, due to the use of heated air, *i.e.* an increase of 100° F. in furnace

temperature produces a final gas temperature which is reduced by 20 per cent., assuming that the boiler load remains constant.

Another important point is the increase in the radiant heat transmission due to increased furnace temperature. With certain types of boilers the transmission of radiant heat to the two bottom rows of tubes, representing from 5 to 10 per cent. of the total heating surface, is about 40 per cent. of the total heat in the fuel.

The limitations in furnace temperature are governed by the fusion point of the ash, excessive wear and tear with the brickwork, as also the suitability of the mechanical stoker, but as a general rule the furnace temperature could be advantageously increased by the employment of heated air, to the extent of, say, 200° F., without introducing any material difficulty in connection with ash, brickwork or the furnace. The heat transmitted by radiation for an absolute temperature of 2730° F. is about 30 per cent. greater than that corresponding to an absolute temperature of 2530° F.

The importance of securing and maintaining a high furnace temperature is thus referred to by Izart in his excellent work, "Méthodes économiques de combustion dans les Chaudières à vapeur." [1]

"In a steam boiler it is important to maintain a high furnace temperature, as the rate of heat transmission through the plates is directly proportional to the difference in temperature between the two sides; that is to say, between the temperature of the water on the inside and the furnace gases on the outside. It therefore follows that for a given gas velocity in the furnace, the more the temperature is increased the more heat passes in the same time to the water in the boiler, and consequently less loss of heat to the chimney. In short, the coal would be better utilised. Besides this important effect, a high temperature assures the combustion of the gases of distillation from the coal in the furnace. These combustible gases have in general a high ignition temperature, and if the furnace temperature is relatively low, or if they should come too rapidly in contact with the plates of the boiler, they will pass to the chimney unburned and cause additional loss.

"Thus the cooling of boiler furnace by excess air is not only bad because of the heat loss in this excess air, but also because the rate of utilisation of the fuel is diminished."

The principal reason why air heaters have not been more extensively adopted in connection with steam boiler installations are :—

(1) The advantages of using heated air for combustion are not yet generally appreciated.

(2) It has been felt that the highest economy would be secured by utilising waste heat for heating feed water.

(3) A disinclination to so reduce the temperature of the waste gases as to render the use of mechanical draught imperative.

There are at present four systems of air heating on the market in this country. The Usco air heater, made by The Underfeed Stoker Co., Ltd.; the Thermix air

[1] See "Méthodes économiques de combustion dans les Chaudières à vapeur," by Izart.

heater made by The Emile Prat Daniel Co., Ltd., Paris ; the Howden Ljungstrom system, and Green's air heater, made by Messrs E. Green & Sons, Ltd.

Fig. 146.—Heating Element, The Usco Air Heater.

The Usco Air Heater.—The Usco air heater consists of a series of plate elements each of which is a narrow semi-circular plate box or chamber of sheet steel of rigid construction, as shown in the illustrations, Figs. 146 and 147.

Fig. 147.—The Usco Air Heater.

The air to be heated is arranged to be passed in a semi-circular path through the elements while the hot gases sweep along its outer surfaces, the elements are placed parallel to the direction of the flow.

The air space through an element is about one inch in width, and midway in this is placed a so-called thermal diaphragm or radiation plate which it is claimed very considerably increases the heating effect.

The complete air heater comprises an aggregation of the elements placed parallel and suitably spaced. The tops or open ends of the elements are so joined together that when connected to the air conduit there is no other possible escape for the air than through the elements.

The battery of elements constituting the air heater is so supported by a rectangular cast-iron frame at the top that the elements are free to expand in every direction. The heater is built into the rear wall of a water tube boiler or set

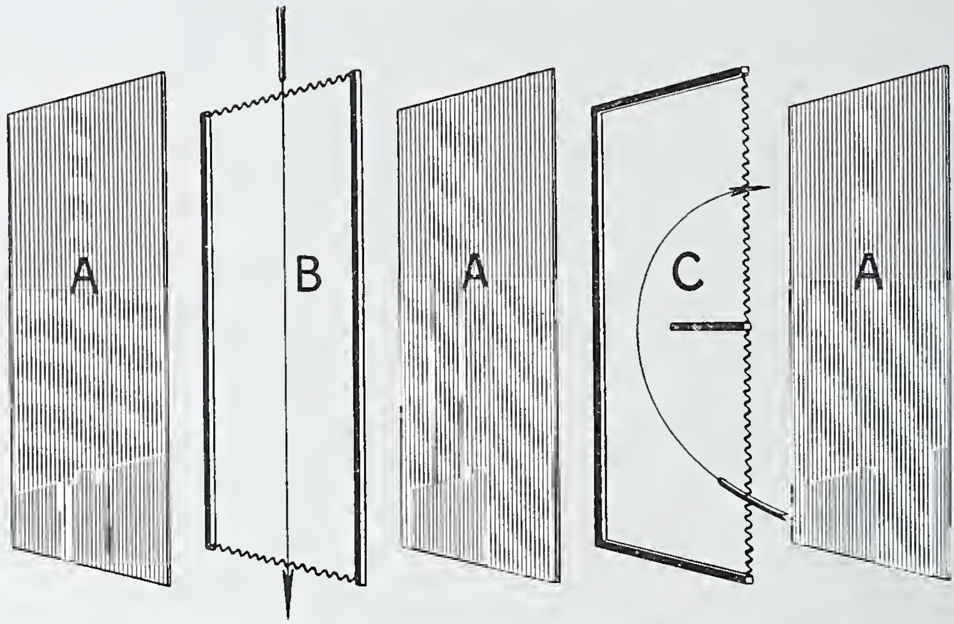


Fig. 148.—The Thermix Air Heater, Heating Elements.

between the boiler and the chimney. The air to be heated is propelled by a fan through the elements of the heater, while the hot gases stream in thin parallel sheets between them.

The semi-circular path through which the air travels through the heater offers but little resistance to its free flow, while the furnace gases pass between the elements in a straight line and without altering their direction of flow. For the removal of soot and ash from the heating surfaces of the elements steam jets are used.

The Thermix Air Heater.—The Thermix air heater, which is illustrated in Figs. 148, 149, and 150, is also a plate or film heater, the heating surface consisting of flat rectangular steel plates about 3 mm. thick separated by distance pieces, which form alternate sections for the passage of the air and the gases.

The distance between the heating surfaces is about one inch. Flexible connections in the form of spirals are used to join the distance pieces together, and while these afford a free passage for the gas and air, they exert a pressure at right angles to the plates, and give a rigid connection between the gas and air elements.

Tests of flue gases made in front and behind these heaters have shown that there is no leakage.

The construction and general arrangement of the Thermix air heater is clearly shown in Figs. 148 and 149. As to the efficiency of film heating for air there can be no question. As will be generally known the co-efficient of transmission increases with increased velocity. The suggested velocity with Thermix heaters is 30 ft. per second against a velocity through economisers which rarely exceeds 5 ft. per second.

Fig. 150 is a sectional view of a boiler installation in an important municipal electricity works, showing Thermix air heaters installed in combination with

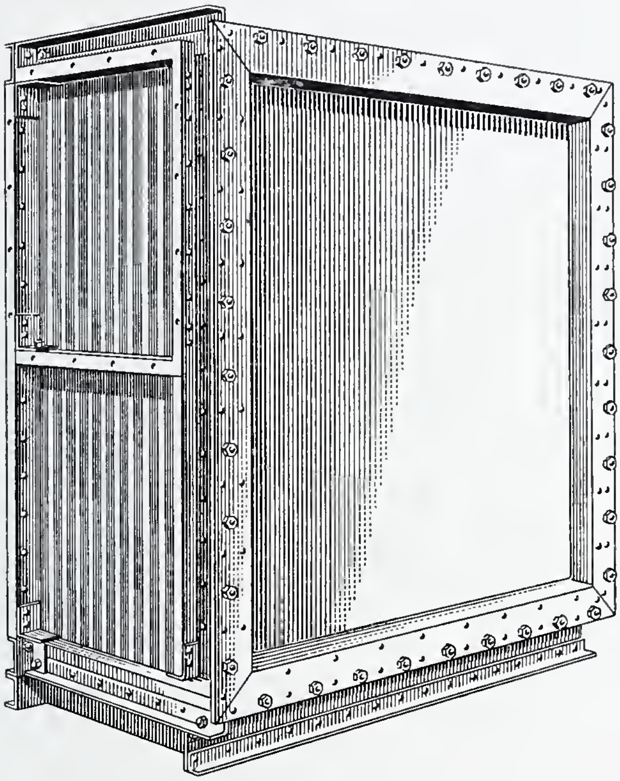


Fig. 149.—The Thermix Air Heater.

Prat draught. Comparative evaporative tests made by the Paris Steam Users' Association on a small Bellville boiler showed a saving in fuel of 13 per cent. and an increased boiler output of 16 per cent. when using the Thermix heater.

At the new Gennevilliers Power Station, Paris, six of these heaters are in use, two of 18,800 sq. ft. of heating surface each, and four of 12,350 sq. ft. each.

There are distinct indications that within the next few years a very considerable advance will be made in the use of heated air for combustion. The insistent demand for higher thermal efficiency, the attainment of which depends upon improved combustion conditions, increased heat transmission, the reduction of chimney loss, as also the reduction of the loss due to unconsumed carbon in the riddlings

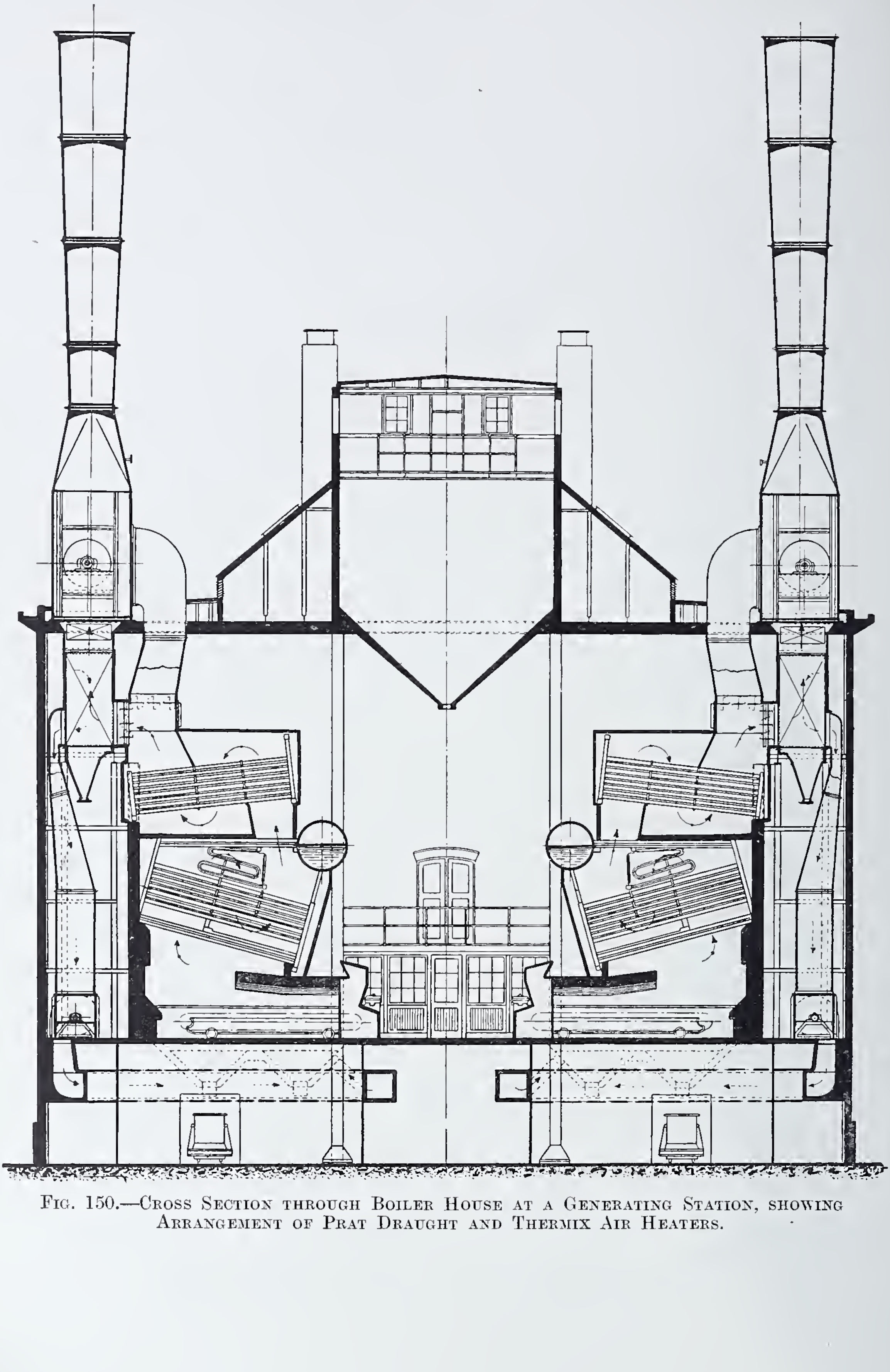


Fig. 150.—Cross Section through Boiler House at a Generating Station, showing Arrangement of Prat Draught and Thermix Air Heaters.

and ash, individually and collectively can only be adequately met by the use of heated air for combustion.

In the effective utilisation of waste heat, and in the reduction of the temperature of the exit gases to an extent which is not practicable with an economiser. owing to the space occupied, and the capital cost, the much more compact heating surface of the air heater and its lower capital cost must ensure its extensive adoption.

The Treatment of Boiler Feed Water.—The character of the feed water supplied to boilers directly affects the consumption of coal, and the use of hard untreated water is responsible for an excessive consumption.

Water is but rarely found which is altogether suitable for boiler feed purposes without some form of treatment. Even a naturally soft water is not *ipso facto*, a proper water for the purpose, it is almost certain to contain free carbonic acid gas, and occluded gases, sometimes organic acids, all of which produce corrosion and pitting.

The chief impurities in water, harmful to boilers, may be summarised as follows :—

(1) *Scale Forming.*—(*a*) Carbonates of lime and magnesium, called temporary hardness, precipitated upon boiling at atmospheric pressure. (*b*) Sulphates of lime and magnesia, called permanent hardness. The former is precipitated at modern boiler pressures, the latter is liable to form double salts, much less soluble than itself, which under the same conditions will be precipitated and lead to scale formation and corrosion.

(2) *Corrosive.*—(*c*) Oxygen in the presence of carbonic acid gas (free and half bound in the carbonates, as referred to under (*a*) above), magnesium and calcium chloride, and more rarely magnesium nitrate, all and separately causing pitting and corrosion. Magnesium and calcium chloride are perhaps the best known corrosive constituents.

Waters containing ferric sulphite or aluminium sulphate, notably for example as generally found in mine waters, are the most virulent corrosive constituents found in natural waters.

All the above are amenable to treatment in modern "softening plant." The scale forming salts, the free carbonic acid gas, and the corrosive salts enumerated above being reduced by the use of lime and soda ash administered in correct proportions. The residual salts left in solution in the treated water are generally speaking chloride and sulphate of soda, which are inert and do no harm, provided the usual routine of blowing down the boilers be carried out. More rarely bicarbonate of soda is found in natural waters in great excess, which upon entering a boiler splits up into free carbonic acid gas, which is corrosive, and carbonate of soda which causes priming, and attacks boiler mountings. This impurity has to the author's knowledge been successfully dealt with by a firm specialising in purifying plant, by reducing the bicarbonate of soda to insoluble sludge in the purifying plant, imparting residual sodium chloride to the treated water.

It cannot be too strongly emphasised that feed water should be treated *before* being supplied to the boiler. It is no part of the function of a steam boiler to treat

feed water, and the use of boiler compounds for this purpose is most undesirable without competent advice.

In any case such procedure is only justifiable in connection with very small installations, and whenever used boiler compound should be introduced continuously, and not in bulk periodically.

Boiler composition does not *remove* impurities but merely changes the nature of the eventual deposit which is precipitated. Generally speaking, boiler insurance

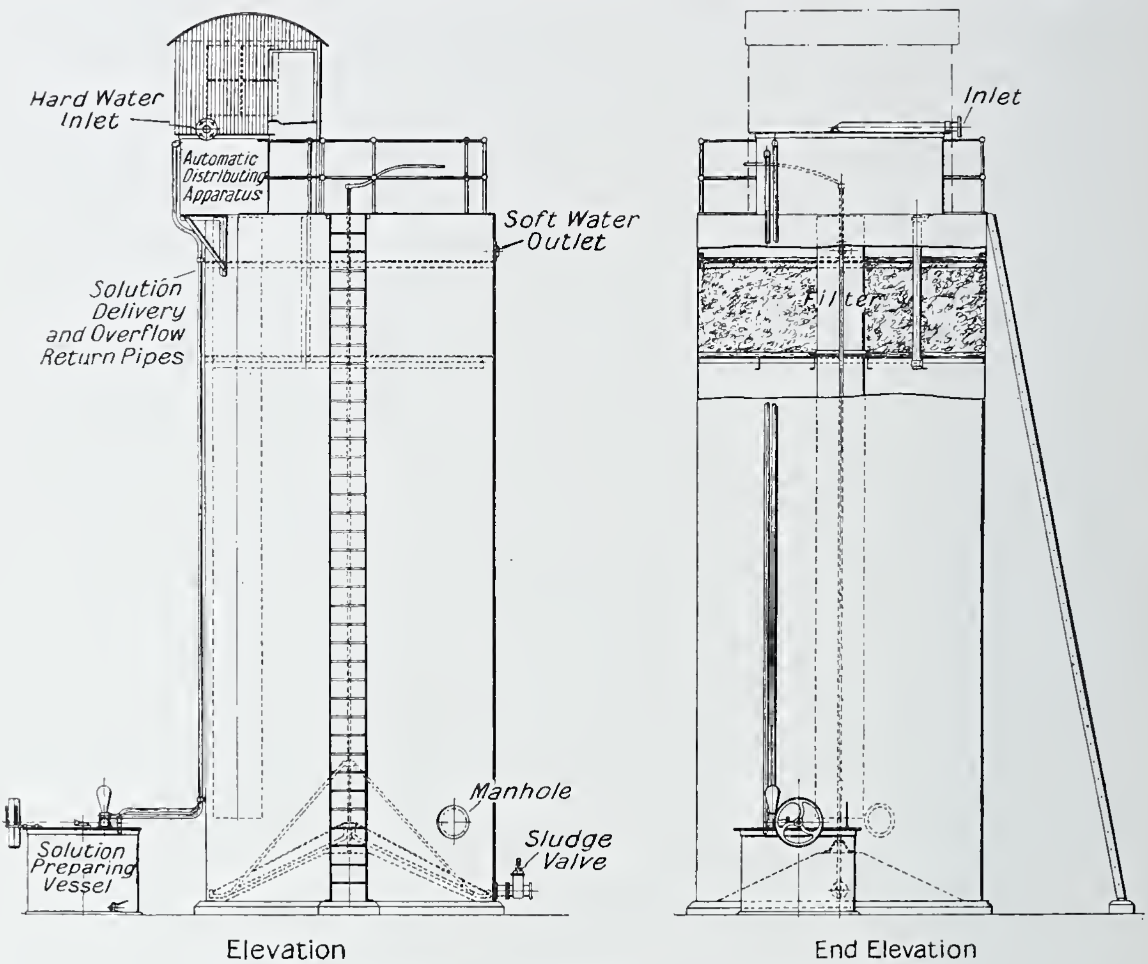


Fig. 151.—Boby's "C" Type Vertical Water Softener.

companies view with disfavour the use of compounds because of possible chemical reaction with impurities present in the water, and consequent damage to the boiler.

A water softener should embody the following characteristics :—

(1) Certainty and accuracy of automatic action at all loads, from no load to full load ; (2) adequate reaction and sedimentation space ; (3) a properly designed filter ; and (4) proper sludge ejecting arrangements.

The Boby Water Softener.—In the Boby softener type, C, illustrated in Fig. 151, the reagent is first prepared as a cream of lime and soda in a separate vessel and delivered to the automatic apparatus which administers a correct dose of the

reagent to the incoming water, the whole operation being controlled by the incoming water.

Unusual accuracy is ensured by this system, the water passes to the reaction chamber and thence through a well-designed filter of adequate proportions. The resulting water is correctly softened, treated, and clarified. Any accumulation of sludge is prevented by sludge expelling gear.

In another type of Boby softener, illustrated in Fig. 152, cream of lime and

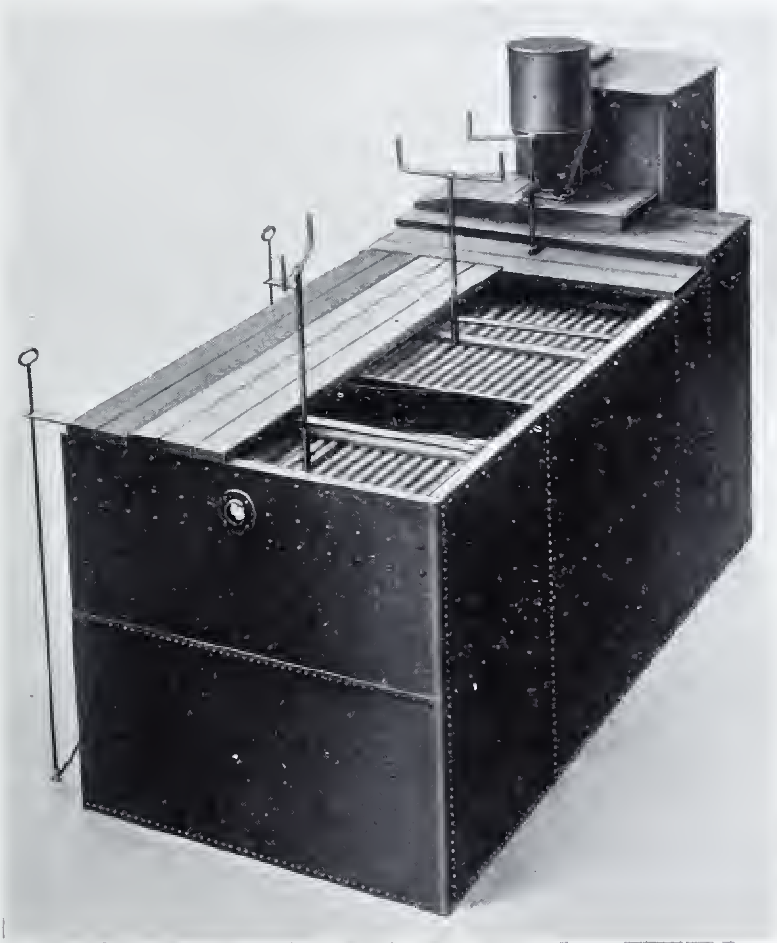


FIG. 152.—BOBY'S TYPE "K" WATER SOFTENER.

soda are replaced by reagents administered direct as dry powder, presenting an automatic, very clean, and simple mechanism, very suitable for moderate capacities and great fluctuation in load.

Oil Elimination.—The importance of eliminating oil from the return from surface condensers, which is to be used for feed water, cannot be too strongly emphasised.

If there is the slightest risk of such contamination, an oil eliminator should be employed. The mechanical process is much the same as for water softening,

the reagents used being generally alumina sulphate, soda ash, and hydrate of lime. The alum coagulates the oil, is neutralised by the soda ash, and the lime eliminates the free carbonic acid gas formed in the reaction. The effluent is generally filtered through a mechanically operated quartz filter.

The Loss due to Scale Formation.—It is scarcely necessary to emphasise the insulating effect of scale in steam boilers, and the resistance offered to the transmission of heat. Scale $\frac{1}{6}$th of an inch in thickness increases the fuel consumption to the extent of 16 per cent., while scale $\frac{1}{4}$th of an inch thick necessitates burning 50 per cent. more fuel. The formation of scale effects a material reduction in the heating surface, as also in the volume of water contained in the boiler. For instance a 4-in. boiler tube has an internal area of 141 sq. in. per foot run. When coated with scale $\frac{1}{4}$ in. thick the area per foot run is reduced to 122 sq. in.

Assuming a water tube boiler having 3000 sq. ft. of heating surface, with an average deposit of $\frac{1}{4}$ in. of scale, the actual heating surface is reduced about 11 per cent., the water capacity is about 12 per cent. less, and the fuel consumption is increased to the extent of about 50 per cent.

Overheating, due to scale, results in the stretching of tubes, due to the pressure inside, and loss of ductility of the steel, which eventually becomes crystalline.

Automatic Feed Water Regulation.—The provision of automatic feed water regulators in connection with water tube boilers is now becoming common practice, and comparatively few boilers of this type, excepting of small capacity, are now being installed without automatic feed water regulators.

Under ordinary boiler feed conditions it is necessary for the attendant to carefully watch the water gauges, when the water level has dropped the check valve is slightly opened and the rate of feed increased. Similarly, if the water level has risen the check valve is slightly closed and the rate of feed reduced.

When the rate of feed is increased through the water level falling, more water is fed into the boiler than is being evaporated, in other words the rate of evaporation does not synchronise with the rate of feed. This involves a drop in the steam pressure, which in turn must be met by increasing the rate of firing. For the time being the boiler is forced, with an inevitable sacrifice in efficiency, because a larger quantity of fuel has to be burned for the same output than would be necessary if the rate of feed were always in exact proportion to the rate of evaporation.

It is true that the extra weight of fuel burned may be small, but under normal working conditions this loss, due to irregular water level, is frequently happening.

Without automatic feed water regulation it is not possible to closely follow the demands of a boiler under fluctuating load conditions, even if the attendant exercises ordinary care, because he usually has other duties.

The purpose of the automatic feed water regulator is to ensure under all conditions that the rate of feed inlet shall always be in exact proportion to the steam output. It is now generally recognised that these conditions are essential in order to operate a boiler with high efficiency, and for this reason, automatic regulation is being extensively adopted.

Feed Water Heating.—There is no more certain and definite means of reducing fuel consumption than by heating the boiler feed water, particularly when the heat thus utilised would otherwise be lost. Feed water may be heated by utilising exhaust steam, flue gases from boilers, or other sources, the hot well discharge from condensing engines, and the drainage from heating apparatus, steam mains, etc. The fuel saving which can thus be effected is clearly shown in the accompanying Table, No. 41.

Green's Economiser.—Green's well-known fuel economiser, which has been very widely adopted and which is illustrated in Figs. 153, 154, and 155, is virtually an extension of the boiler heating surface. It has been frequently observed that

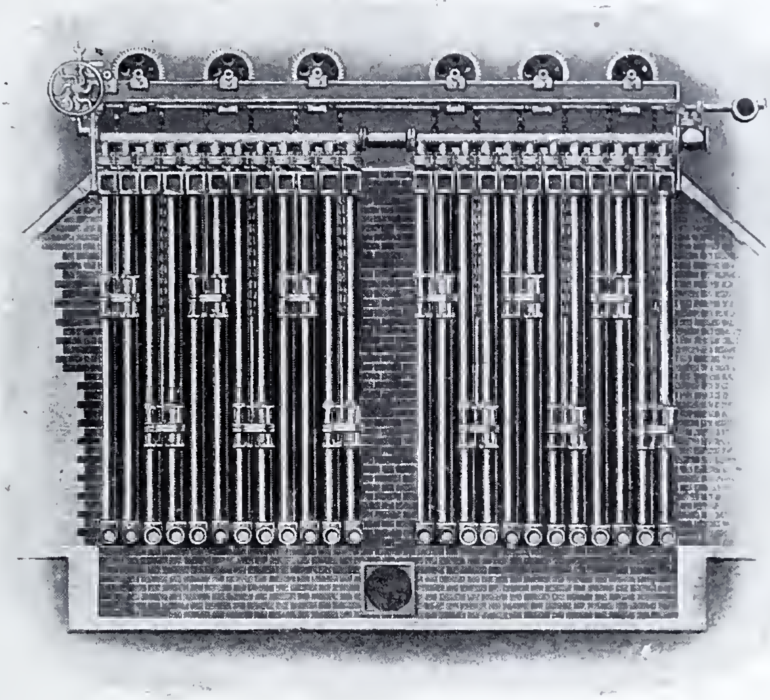


FIG. 153.—GREEN'S FUEL ECONOMISER, SECTIONAL ELEVATION.

had it not been for our wasteful methods in industrial fuel consumption, and accordingly the very serious loss shown in the discharge of high temperature gases from the boiler to the chimney, this well-known apparatus would not have been needed.

The standard economiser consists of a series of cast-iron pipes usually 9 or 10 ft. in length, the external diameter being $4\frac{9}{16}$ in. and the internal diameter $3\frac{11}{16}$ in. The pipes are arranged in rows, each row comprising four or more pipes, depending upon the size and arrangement. The sections comprising each row of pipes are made up by forcing the pipes by hydraulic pressure into junction boxes or headers, the ends of the pipes being turned, and the sockets in the junction boxes accurately bored to receive them, thus forming a tight metal to metal joint.

When erected in position the sections are connected by their top and bottom

headers to multiple flanged branch pipes. The bottom headers project through the front wall of the economiser chamber, and access for cleaning purposes is provided by means of access lids on the branch pipe opposite to each header.

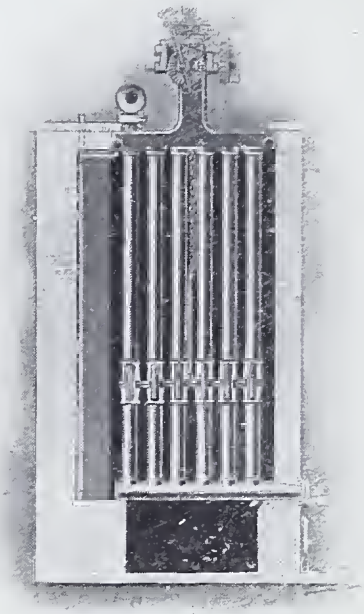


Fig. 154.—Green's Fuel Economiser. End Elevation.

The water is admitted to the economiser through the bottom branch pipe to the sections and is collected in the top branch pipe, passing thence to the boiler feed water main.

Thermometer pockets are provided at the inlet and outlet ends of the bottom and top branch pipes. The flow of water through the economiser and the gases over the heating surface is in opposite directions, the feed water being introduced at the end nearest the chimney, and taken out at the opposite end, nearest to the boiler.

For the external cleaning of the pipes, scrapers are used, these being carried on chains and actuated by means of a small steam engine or electric motor. The power required is very small, and it is desirable to use the scrapers continuously. One or more safety valves are fitted according to the size of the economiser; similarly one or more blow-off valves are provided and so arranged as to completely drain the economiser.

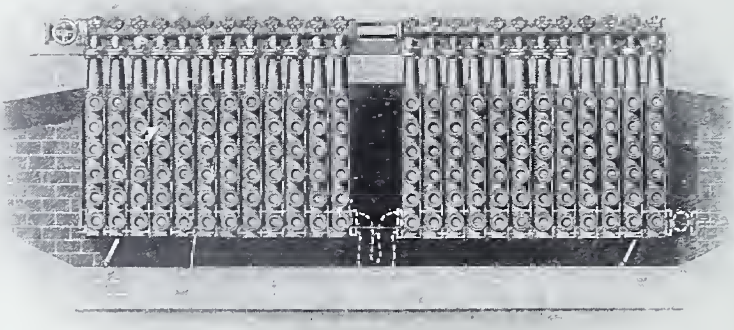


Fig. 155.—Green's Fuel Economiser, Plan.

Water from these valves should be carried away and not allowed to drain into the soot pit; this discharge should also be visible so that any valve leakage may be detected.

The inlet temperature of the water supplied to the economiser is of much

importance; obviously the maximum advantage in heat exchange and recovery would be obtained with a cold feed. In practice, however, it is found that unless the inlet water supply is hot, say from 100° to 130° F., there is a serious risk of "sweating," or external corrosion, and wastage of the pipes, this being due to the sulphur content of the gases and condensation.

It has been frequently observed that the installation of an economiser spoils the chimney draught. To some extent this is true, but obviously it depends upon three factors :—

(1) The average temperature of the gases before entering the economiser, (2) the heating surface provided in the economiser, or in other words its capacity, and (3) the average temperature beyond the economiser. Certain it is that if the

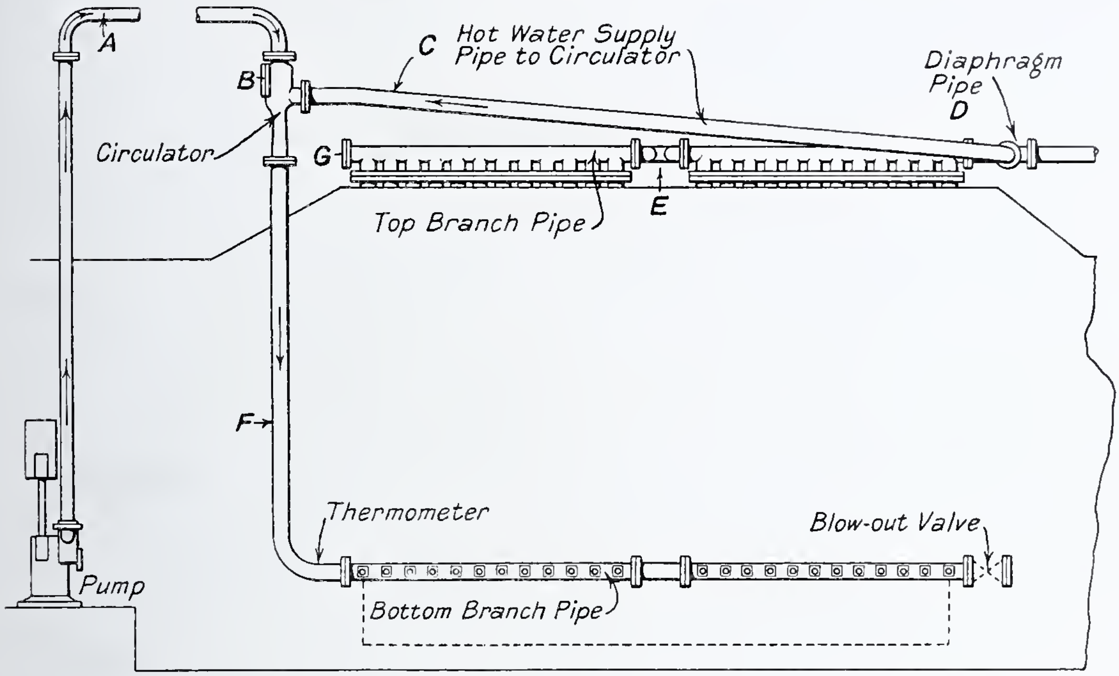


Fig. 156.—Application of the "National" Circulator to a Green's Economiser.

gases under natural draught conditions are discharged into the chimney at a temperature below 350° to 400° F. the natural draught will not be satisfactory.

Some of the draught troubles which have been attributed to the economiser in reducing the temperature of the gases to too low a point, are in fact due to excessive air infiltration at boiler settings, in flues, and in the economiser setting. This air dilution and cooling is so common and widespread that it is probably the cause of far more natural draught troubles than can be directly traced to the economiser.

It is important to take steps to reduce to the minimum the air leakage at economiser scrapers.

The National Circulator.—The importance of providing feed water to the economiser at a temperature of not less than 100° F. has already been referred to. The apparatus which is now being extensively adopted for regulating the feed

water inlet temperature is the National Circulator, which is made by the National Boiler Insurance Co., Ltd.

This circulator is a special form of injector which is fixed in the feed pipe range between the pump and the economiser as illustrated in Fig. 156. The connection of the circulator to the top branch of the economiser is generally arranged, as shown in the illustration by the pipe marked C, to the diaphragm pipe D.

In some cases, such as small economisers, the connection of the circulator to the top branch pipe may be made through an expansion bend E, or to a specially made cap on one of the top branch pipe openings, or alternatively from the opposite or cold end of the top branch pipe G.

TABLE No. 41

Percentage Saving effected by Heating Feed Water

Feed Temperature.	Initial Temperature of Feed Water.											
	40	50	60	70	80	90	100	120	140	160	180	200
100° Fahr.	5·1	4·285	3·456	2·616	1·758	·887	·00	..	..	..	..	..
120° ,,	6·8	5·999	5·184	4·36	3·516	2·661	1·79	·00	..	..	..	..
140° ,,	8·5	7·713	6·912	6·104	5·274	4·435	3·58	1·822	·00	..	..	..
160° ,,	10·2	9·427	8·64	7·848	7·032	6·209	5·37	3·644	1·858	·00	..	..
180° ,,	11·9	11·141	10·368	9·592	8·79	7·983	7·16	5·466	3·716	1·892	·00	..
200° ,,	13·6	12·855	12·096	11·336	10·548	9·757	8·95	7·288	5·574	3·784	1·93	·00
220° ,,	15·3	14·569	13·824	13·08	12·306	11·531	10·74	9·11	7·432	5·676	3·86	1·968
240° ,,	17·0	16·283	15·552	14·824	14·064	13·305	12·53	10·932	9·29	7·568	5·79	3·936
260° ,,	18·7	17·997	17·28	16·568	15·822	15·079	14·32	12·754	11·148	9·46	7·72	5·904
280° ,,	20·4	19·711	19·008	18·312	17·58	16·853	16·11	14·576	13·006	11·35	9·65	7·872
300° ,,	22·1	21·425	20·736	20·056	19·338	18·627	17·9	16·398	14·864	13·24	11·58	9·84

The circulator works better without a valve in pipe F, between the circulator outlet and the inlet to the bottom branch of the economiser, but if it should be necessary at times to cut out the economiser, a valve of the through-way type should be fitted in the hot water return pipe C, and also between the pipe F and the bottom branch pipe of the economiser. Fig. 157 illustrates the National Circulator, which is made in four sizes.

Exhaust Steam Feed Water Heating.—The utilisation of exhaust steam for feed water heating has already been referred to. Figs. 158, 159, and 160 illustrate the well-known high velocity exhaust steam feed water heater made by Messrs Holden & Brooke, Ltd.

Two features of importance in connection with this heater are :—(1) The long water travel, and (2) the high velocity at which the water travels through the heater.

The heater illustrated in Figs. 158 and 159 has twelve groups of four tubes each; the dotted lines shown in the plan indicate the compartments in the lower chamber

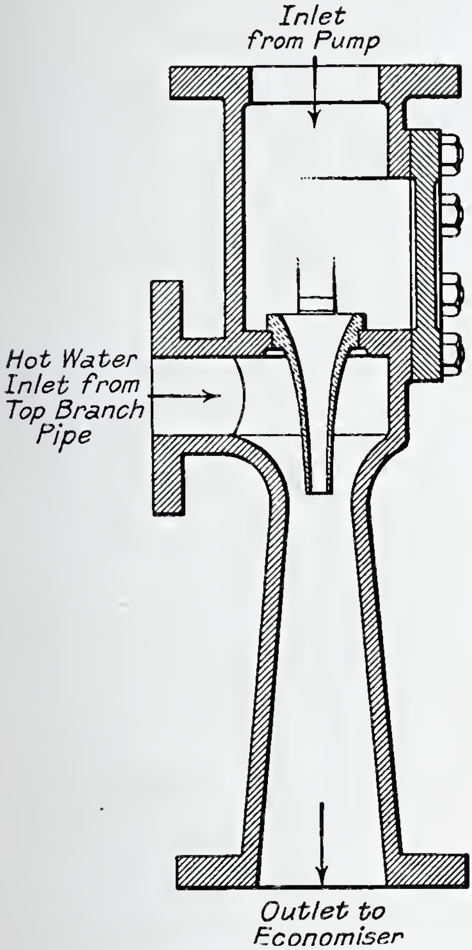
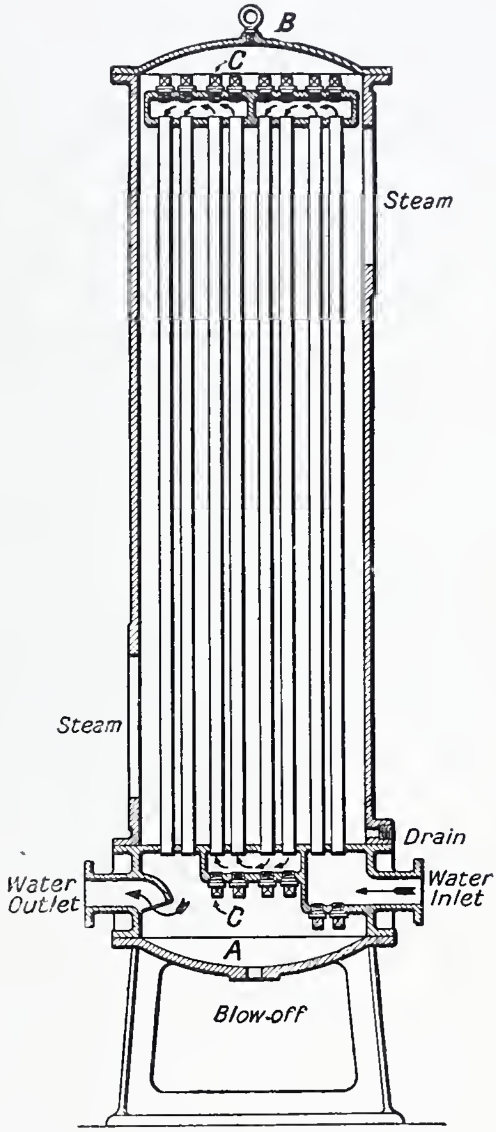


FIG. 157.—THE NATIONAL CIRCULATOR.



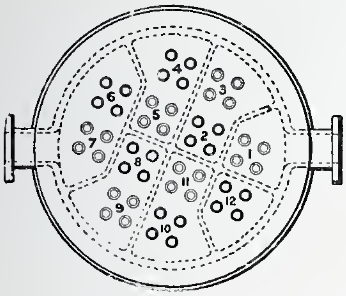


FIG. 159.—HOLDEN & BROOKE'S HIGH VELOCITY EXHAUST STEAM FEED-WATER HEATER, PLAN.

FIG. 158.—HOLDEN & BROOKE'S HIGH VELOCITY EXHAUST STEAM FEED-WATER HEATER.

to which the tubes have access. The tubes through which the water flows upwards are indicated by the thin double lines, and the tubes in which the water flows downwards by the heavy single line.

The water enters the right-hand branch, passes up the set of tubes marked 1, and down the set marked 2, up those marked 3, and so continues the double flow, until finally passing down the set of tubes marked 12, and out at the water outlet branch on the left-hand side. The floating head is suitably chambered, to permit of the alternate upward and downward flow. These heaters, which are also made of the horizontal type, are, when fitted with strengthened bodies and covers, suitable for use with live steam.

Apart from the actual reduction in fuel consumption, heating the feed water increases the capacity of the boiler. For instance, increasing the feed temperature

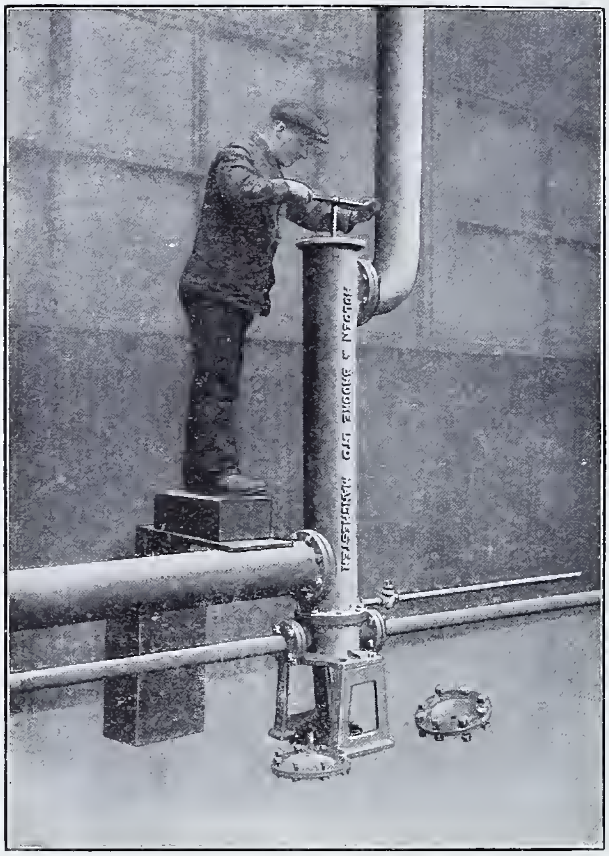


FIG. 160.—HOLDEN & BROOKE'S HIGH VELOCITY EXHAUST STEAM FEED-WATER HEATER.

from 50° to 210° F. not only reduces the fuel consumption to the extent of about 14 per cent., but also increases the steaming capacity of the boiler by approximately 16 per cent.

Feed Water Measurement.—The measurement or weighing of feed water used is essential in connection with every steam boiler plant. For the small plant this may be periodical, for all other steam boiler plants means should be provided for continuous measurement, and it is preferable that the apparatus employed should be of the recording type.

The simplest methods of measuring feed water for periodical evaporative tests

will be discussed later in this chapter under the heading of "Instruments and Testing."

Boiler feed water measuring and weighing apparatus may be said to comprise three distinct types:—(1) Closed meters, which are volumetric, (2) tank meters or flow recorders, and (3) tanks containing a given and invariable weight of water, which is automatically recorded when discharged into the feed tank.

Kent's Uniform Positive Water Meter.—This type of water meter, which is of the rotary balanced piston type, is made for cold and hot water, and has been very extensively adopted for the measurement of boiler feed water; it is, in fact, so well known that it is unnecessary to describe same.

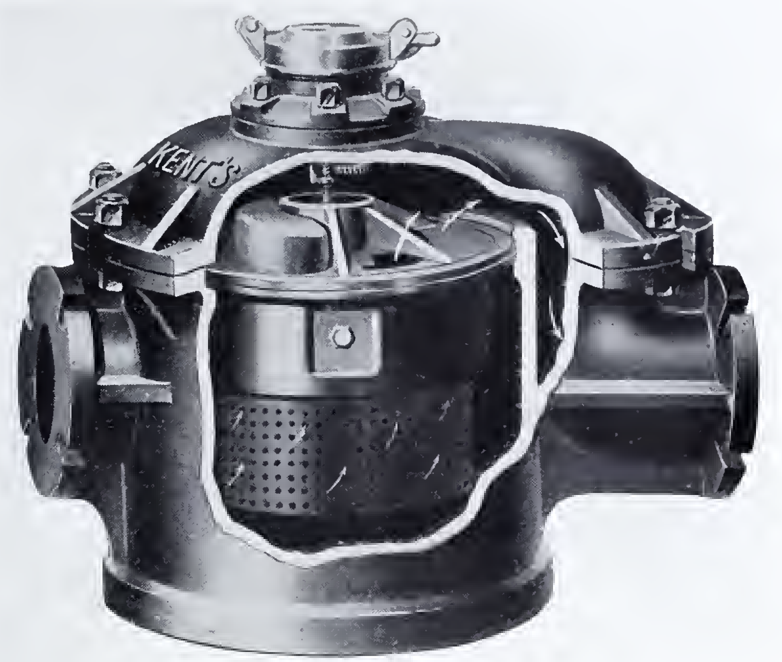


Fig. 161.—Kent's Uniform Positive Water Meter, Cold Water Type.

In Fig. 161 is shown a meter of the cold water type, the arrows indicating the direction of the flow.

The hot water meter is of the same design, but the outer cast-iron casing is made specially strong.

Kent's Venturi Water Meter.—This well-known type of meter consists of two parts only, the Venturi tube, which is fixed in, and becomes part of the feed pipe line, and the recording apparatus, which is illustrated in Fig. 162.

The Venturi meter is based upon the hydraulic law, that with water passing through a pipe of gradually diminishing area, the velocity is increased, with a corresponding reduction in the lateral pressure.

The exterior of the tube is provided at the throat and at the inlet or up stream end, with annular pressure chambers. These communicate with the interior tube

by small holes, which are bushed with vulcanite to prevent incrustation. The interior end of these bushes are made perfectly flush with the inside of the tube.

The pressure in these respective chambers is therefore the same as that in the

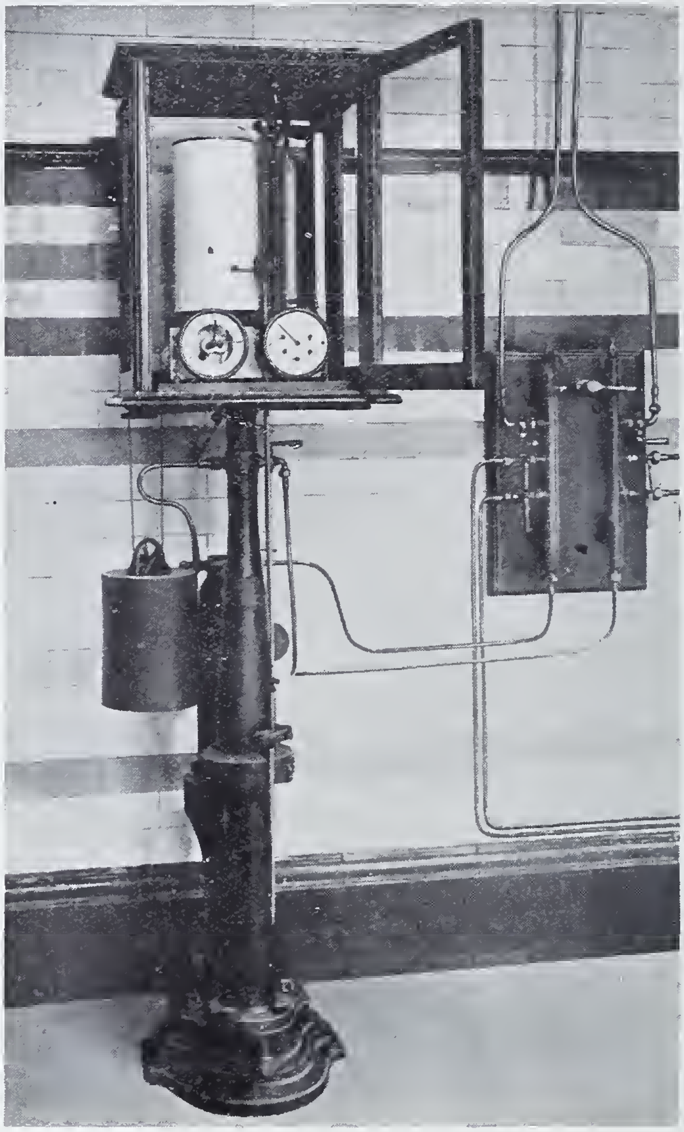


Fig. 162.—Kent's Venturi Water Meter, Recording Apparatus.

throat and at the inlet end of the Venturi tube. Small pipes, preferably of copper, convey these pressures to the recording apparatus.

The recording instrument may be fixed anywhere within 1000 feet of the tube, or, if desired, the registration can be conveyed electrically for any distance.

The Lea V Notch Recorder.—The Lea recorder has been very widely adopted during the past few years for the continuous measurement and recording of boiler feed water.

This well-known apparatus, which is illustrated in Figs. 163 and 164, gives a permanent record of the rate of flow of water in pounds per hour, the depth of water in inches, flowing in a V notch, being accurately and continuously measured and recorded. The rate of flow through V notches is deduced from Thomson's formula,

$$\text{Cubic feet per minute} = 0{\cdot}305\ H_2 \sqrt{H} \quad \text{where } H = \text{depth in inches.}$$

The recording instrument is actuated solely by the rise and fall of a float connected with a tank containing a V notch, the float being attached to a spindle

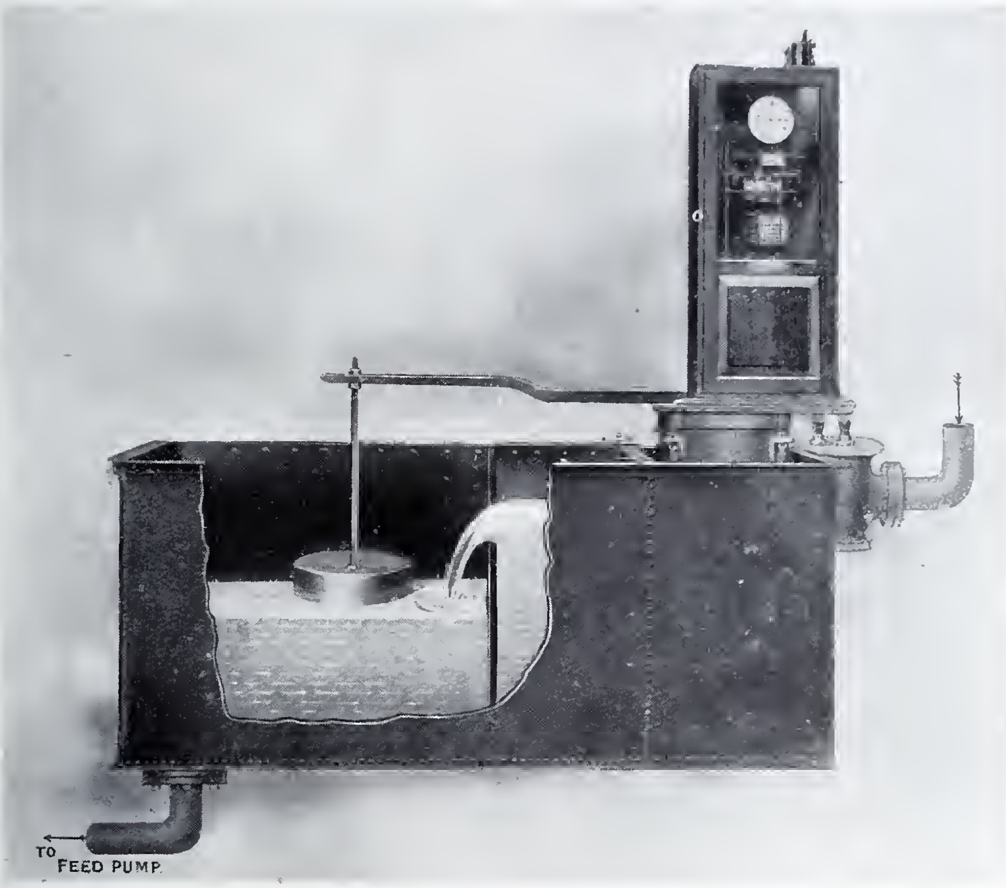


Fig. 163.—The Lea V Notch Recorder.

which passes through the bottom of the instrument case. The float spindle is provided with a rack which gears into a small pinion upon the axis of a drum, which drum has a screwed thread upon its periphery.

The contour of the thread is the curve of flow for the notch, and just as the flow through a notch increases rapidly with its depth, so the pitch of the screw increases *pro rata*. Above the spiral drum is a horizontal slider bar supported upon pivoted rollers, and carrying an arm which is provided with a pen point, in contact with a chart upon a clock driven recording drum.

As the float rises the movement of the spiral drum is imparted to the pen arm by the saddle arm, which engages at its lower end with a screwed thread.

The recording pen moves in direct proportion to the flow, producing a diagram

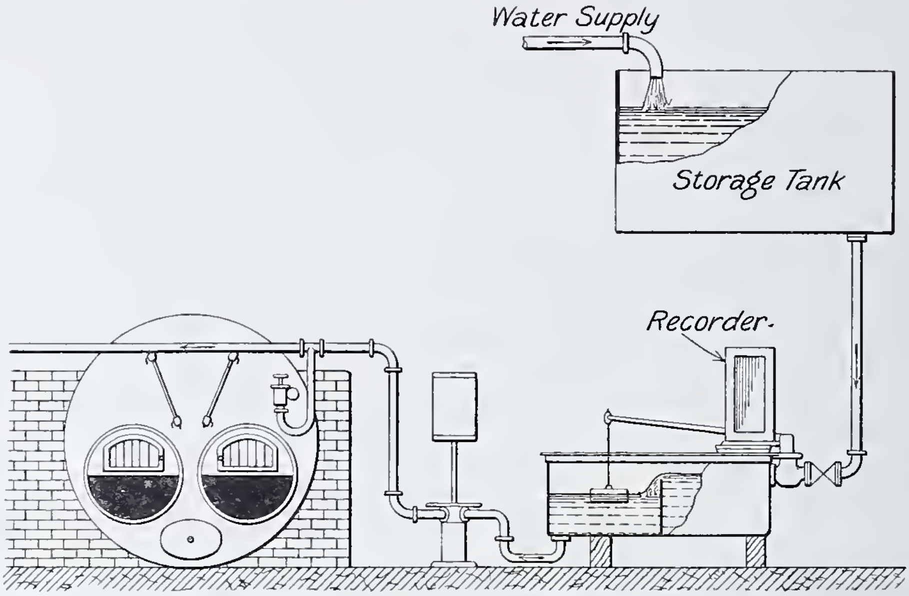


FIG. 164.—THE LEA V NOTCH RECORDER.

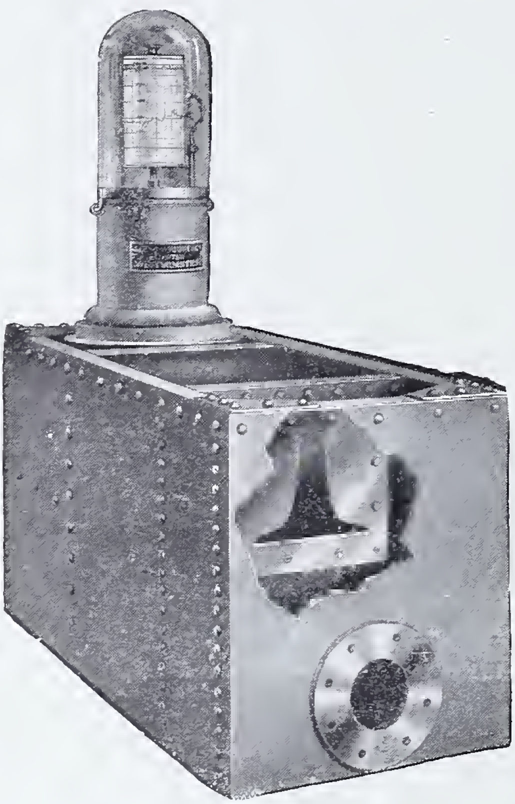


FIG. 165.—THE YORKE WEIR WATER METER.

whose area is a measure of the total flow, each square inch on the chart representing a given weight of water in pounds.

With the Lea recorder the water is always measured on the suction side of the feed pipe, *i.e.* where it is not under pressure.

The Yorke Weir Water Meter.—The Yorke weir water meter, illustrated in Fig. 165, is, as its name implies, of the weir type, the notch, however, instead of being cut V shape is of the shape shown in the illustration.

With this type of water meter the weir has a breadth inversely proportional to the square root of the corresponding head, with the result that the head is directly proportional to the flow. The rate of flow is recorded by means of a float which is arranged to directly move a pen up and down a drum, which is rotated by an eight-day clock mechanism.

No correcting mechanism is required

between the float and the recording pen. The meter is exceedingly simple and it is claimed that it is very accurate. National Physical Laboratory tests showed that the inaccuracy does not exceed 1 per cent. Meters of this type are practically

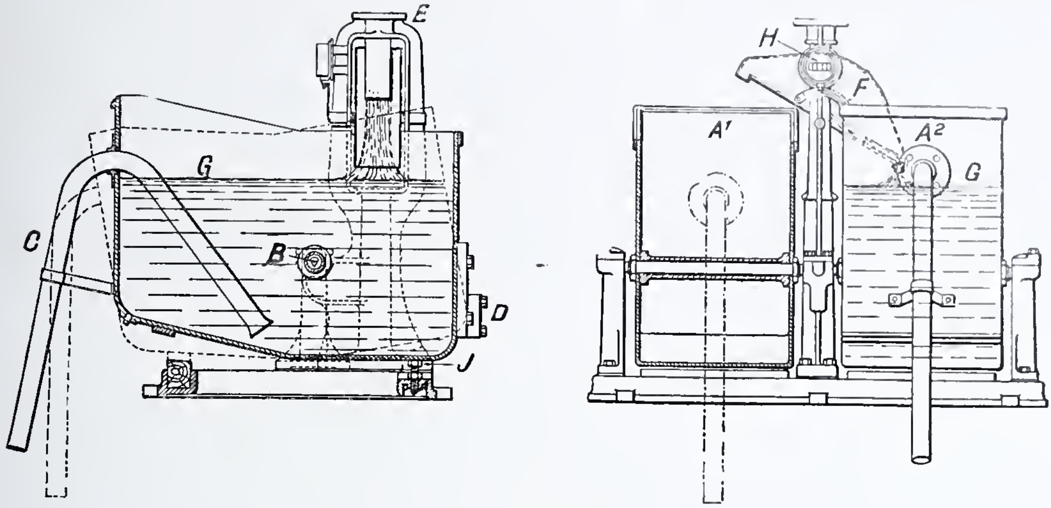


Fig. 166.—The Leinert Water Meter.

self-compensating in so far as temperature variations are concerned, owing to the fact that when the temperature of the water increases, its density is reduced; on the contrary, when the temperature falls the density increases, affecting the buoyancy of the float.

The Leinert Meter.—The Leinert meter is a good example of type No. 3 referred to above, in which all water is weighed and the quantity of water discharged is automatically recorded on a counter. The operation of this meter is not appreciably affected by slight changes in specific gravity, or variations in the temperature of the water.

Fig. 167.—The Leinert Water Meter.

The apparatus is actuated by the dead weight of the liquid measured, and this being an invariable figure, the meter is not subject to inaccuracies. It is claimed that its accuracy is permanent, inasmuch as it does not depend upon adjustment or the wear of its parts. It is not affected by grit and impurities, and can be readily cleansed. The Leinert meter, illustrated in Figs. 166 and 167, comprises two tanks of equal size (A^1 and A^2), see Fig. 166, each swinging independently upon a pair of knife edges B, which form an axis dividing the tank into two unequal and unbalanced parts. Each tank is fitted at the front end with one or more syphon pipes C, and at the back with an adjustable weight D

The liquid to be measured enters at the inlet E, and passes along the chute F, into one or other of the tanks, for instance as shown in Fig. 166, into the right-hand tank A^2. The weights D are so adjusted that when a tank is being filled with water up to about the height marked G in Fig. 166, it remains in a horizontal position, but as the weight of liquid increases by the continued flow, the tank tilts forward into the position shown by the dotted lines in F, when the water is discharged through the syphon pipe.

After the syphon has been started and the level of the water has fallen sufficiently, the tank resumes its original horizontal position by the influence of the balance weight D, the syphon continuing in action until the tank is emptied.

As each tank tilts forward it throws the chute F over, so that the new water to be measured must fall into the other tank, when the same cycle of operations is repeated. It will thus be seen that both tanks are filled automatically and alternatively with fresh water, while the measured water flows away into a storage or feed tank as required.

The number of times each tank is filled and emptied is registered by a counter H, which is actuated by the alternate movement of the chute.

The chute rests clear of the tank, into which the water is running, so that at the moment the tank commences to tilt no influence can be exercised by the weight of the chute, or by the pressure of the running water in the chute, or by the resistance of the mechanism of the counter. The tilting of the tanks, and consequently the recorded measurement, is entirely dependent upon the introduction into them of a definite weight of water.

The Superheating of Steam.—It is now generally conceded that no steam boiler installation can be regarded as complete and efficient without the provision of a superheater.

The superheating of steam may be briefly described as imparting heat to the steam after it has left the boiler, and when it is no longer in contact with the water. The heat units thus imparted to the steam must of necessity be lost before any condensation can take place.

When steam at the boiler pressure passes through the superheater the rise in the steam temperature is determined by three factors:—(1) The heating surface of the superheater, (2) the temperature of the gases of combustion sweeping the superheater, and (3) the pressure and volume of the saturated steam delivered to the superheater, as also the percentage of entrained moisture present in the steam.

In connection with the boilers of the Lancashire or internally fired type, the superheater is placed in the downtake, where the temperature of the gases usually range from 900° to 1200° F. depending upon the kind of fuel used, the firing equipment, the length of the boiler, the length of the grates, and the rate of combustion.

With water tube boilers the superheater may be placed in any one of various positions, depending upon the type of boiler, the space available, the path and temperature of the gases, and the final steam temperature required. Under average conditions with both Lancashire and water tube boilers, the added superheat required by steam users usually varies from 100° to 150° F., but for the steam

supply to turbines a final steam temperature of from 650° to 750° F. is now frequently demanded.

The most efficient steam temperatures for engines of types commonly used are generally agreed to be as follows :—

For slide valve engines 400° to 450° F., for Corliss valve engines 500° F., and for drop valve engines 600° to 650° F.

The thermal conductivity of superheated steam is lower than that of saturated steam, hence the heat is not so readily transmitted from the body of the steam to the radiating surfaces.

The advantages of using superheated steam may be briefly summarised thus :—

(1) For a given duty *less water* is required, *less steam* has to be generated, and accordingly *less coal* is consumed.

(2) The output required from the boiler is reduced.

(3) Condensation is prevented in engine cylinders and steam pipes.

(4) Steam may be conveyed long distances without condensation.

(5) During short stoppages condensation is prevented.

(6) Leaky joints are prevented.

(7) The efficiency of engines and pumps is increased.

(8) In processes using steam for drying, heating or boiling *when the time element is not an essential feature of the process*, the work is much accelerated and the cost is considerably reduced.

In a very large number of works the possible saving as the result of eliminating condensation losses *alone* is very considerable. It is a common experience to find steam being carried long distances to isolated plant, detached units, and pumps, where the steam consumption could be reduced to the extent of 20 per cent. or even more if dry steam were supplied.

The economy due to superheating with modern plant usually varies from 10 to 15 per cent., while with old and inefficient plant it may be as high as from 20 to 25 per cent. By using steam superheated to the extent of from 50° to 60° F. only, cases have come under the observation of the author where the saving has exceeded 13 per cent.

The importance of a low superheat in the avoidance of condensation loss would not appear to be generally appreciated. With old and low pressure plant and cast-iron steam mains, there is a disposition to avoid the use of superheated steam as unsuitable. If it were proposed to use steam superheated to the extent of 150° F. this attitude would be justified, but there can be no practical objection to the use of dry steam, while the gain in reduced fuel consumption is considerable.

Superheaters vary considerably in design and structure, but generally they may be separated into two distinct groups : (*a*) sectional superheaters, and (*b*) superheaters of the direct expanded in tube type.

For internally fired boilers, while both types are extensively used, the former type offers outstanding advantages, inasmuch as all joints are external, under observation, and readily accessible, while the removal and replacement of sections or elements is greatly facilitated. Further, superheaters of this type provide

flexibility in heating surface, as sections or elements may be quickly removed and plugged or blanked off.

A further feature of importance is the draining of the headers; not only is this of great advantage in preventing the accumulation of water of condensation in the headers, but with dirty or hard boiler feed water deposit and incrustation in the tubes is prevented.

Superheaters of the direct expanded in tube type, while being less expensive to manufacture, offer none of the advantages referred to. If a tube or element fails it cannot be replaced without a stoppage and considerable loss of time.

For water tube boilers, superheaters of the integral type have been widely adopted. Such superheaters, being of the direct expanded in tube type, embody the same limitations and objections as already discussed.

Usually for all final steam temperatures involving an addition of up to 150° F. of superheat, there is no reason why superheaters of the sectional type should not be used. For very high final steam temperatures, considerations of position, space required, and the temperature of the gases frequently preclude the use of this type, which by reason of the joints being arranged externally is not so compact as the integral type.

There can be no doubt that the more general use of superheaters would effect a very considerable reduction in the consumption of fuel, and regarded solely from this point of view a superheater is a very remunerative investment.

Coal Handling.—It is of doubtful advantage to apply mechanical stokers of any type to either one or more boilers unless mechanical means are also provided for handling the fuel from the point where it is tipped or stored, and its delivery into the stoker hoppers.

If economy in the boiler house is desired, the full advantage of machine firing in this direction cannot be realised unless coal and ash handling plant, carefully designed to meet the existing conditions, is provided.

The nature of the equipment will depend upon the size of the boiler plant, and the conditions which have to be met. For single boilers, while it is doubtful if the provision of ash handling plant of any kind is warranted, an independent and automatic type of bucket coal elevator is often of considerable advantage.

For larger installations, whether the coal handling plant shall be of the band, chain, or bucket type, or of a combined type, will necessarily be determined by the individual conditions and requirements, as also the efficient adaptability of a particular type or combination of types.

The Steel Link Conveyor.—The Bennis steel link conveyor, illustrated in Fig. 168, consists of a chain built up of mild steel links, each bent in the form of a "U," which work in a cast-iron trough. The lower part of the chain moves inside a rectangular trough and carries the coal with it. Openings are provided in the bottom of the trough at desired intervals, through which the coal drops into the bunkers, or direct to the mechanical stoker hoppers.

The conveyor trough may be inclined to an extent not exceeding 30 per cent. from the horizontal, and coal may be thus raised from the boiler house floor level

to a suitable height for dropping into the hoppers, without the provision of a special elevator for the purpose. The U link conveyor is very flexible and may be conveniently arranged to meet various requirements.

Bucket Elevators.—Bucket elevators, as illustrated in Fig. 169, are very largely

FIG. 168.—THE BENNIS STEEL LINK CONVEYOR.

used; these may be arranged to deliver coal to the hoppers of each boiler separately or to every two boilers.

Elevators of this type may be set at any convenient angle or curved to suit the angle of delivery required. The Bennis bucket elevator is of the automatic self-starting and stopping type, which is so arranged that over feeding of coal into

the hoppers is prevented. When the stoker hoppers are full the elevator is automatically stopped.

The Gravity Bucket System.—The principal advantage of the gravity bucket

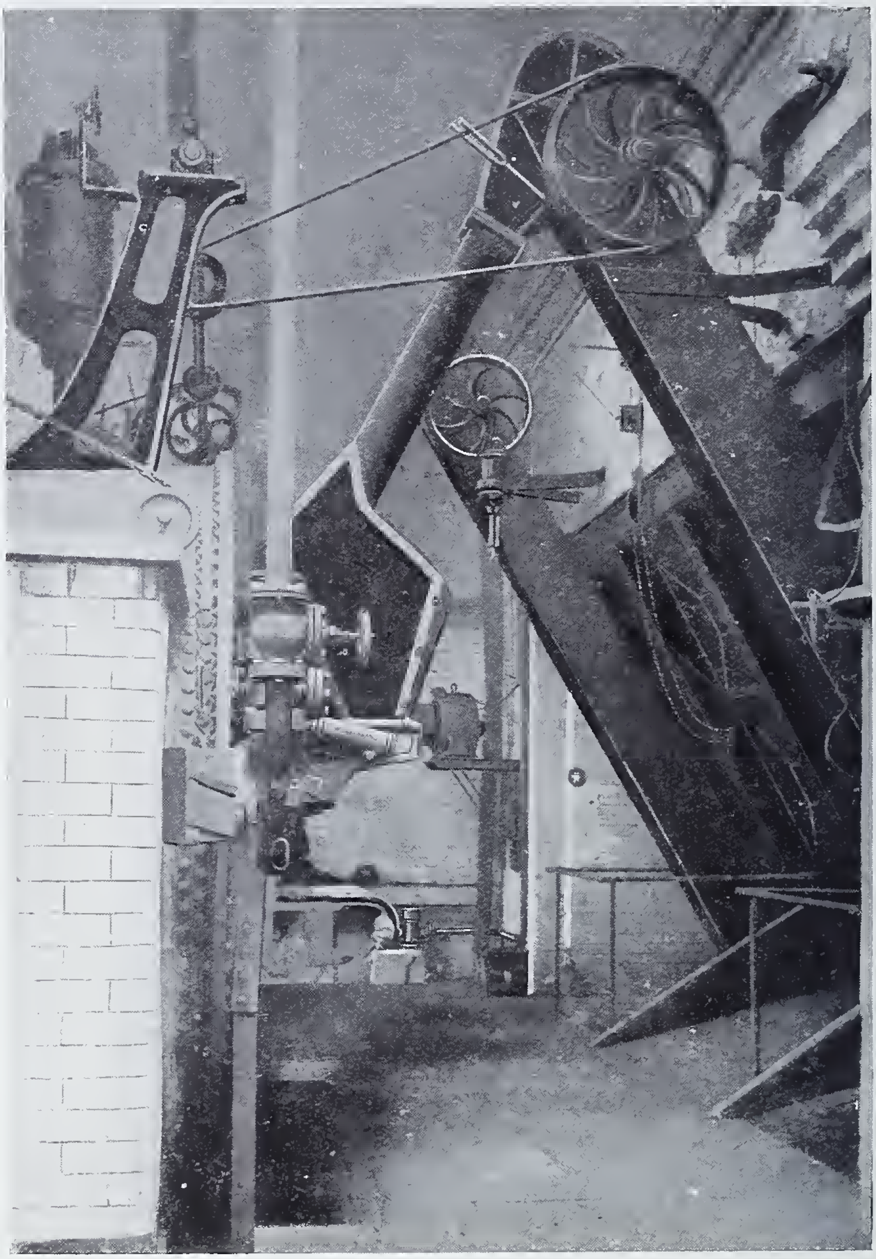


FIG. 169.—THE BENNIS BUCKET ELEVATOR.

system over other forms of elevators and conveyors is that the same means of conveyance may be used for conveying the coal either horizontally, vertically, or at any desired inclination, the buckets being so arranged that they remain upright and preserve their equilibrium in whatever direction the chain may be travelling.

This type of conveyor is practically automatic in its cycle of action, no handling being necessary from the point at which the material is delivered into the receiving hopper feeding the conveyor, until the fuel is discharged to the bunkers, other than the moving of the dumping levers. By the provision of balance-tipping levers, which engage with movable intermediate pins, the buckets can be automatically tipped at any desired point of travel. Further, the conveyor may be arranged to feed the bunkers with coal on the inward journey, and remove the ashes on the return journey.

A gravity bucket conveyor of the Bennis type is illustrated in Fig. 170.

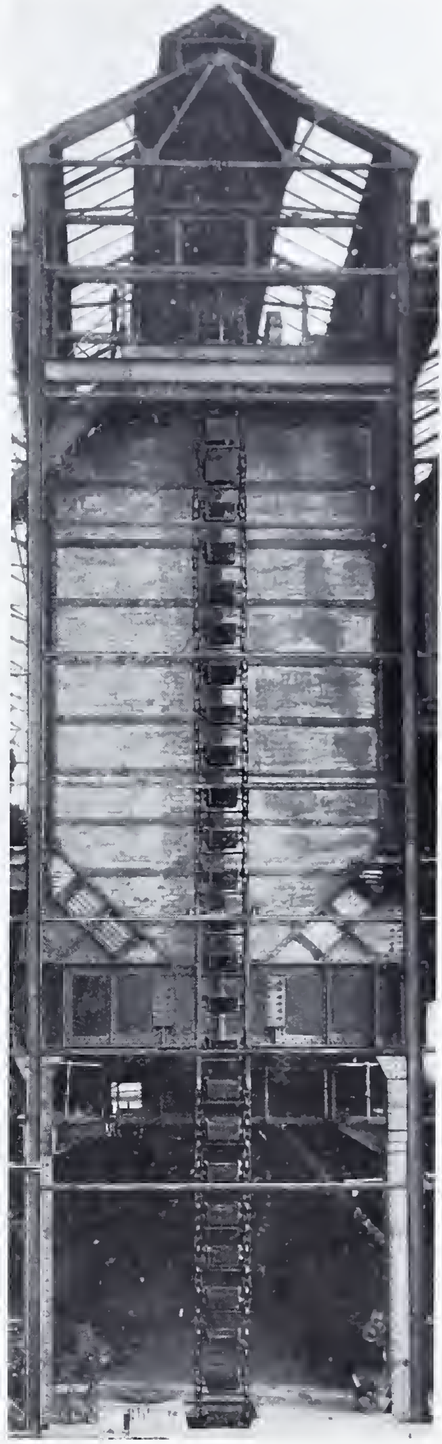


Fig. 170.—The Bennis Gravity Bucket Conveyor.

Portable Elevators.—A portable elevator of the Bennis bucket type is illustrated in Fig. 171. This elevator has a length of 10 ft. between the centres of the drums, and is provided with buckets 8 in. wide. The framework of the elevator consists of rolled steel channels and angles braced together. The top and bottom of the elevator is formed of cast-iron plates, on which the bearings for the shafts are cast. The elevator is mounted upon a portable truck in such a manner that the angle of the elevator may be altered if desired. The truck is built of mild steel sections, and is carried on four rollers, which are attached to pivoted axles. Provision is made for locking the wheels in four positions; the axles work independently of each other.

The elevator is driven by two chain drives. Two sprocket wheels are placed on the pivot shaft. One of the sprockets is driven direct from the motor, the other sprocket drives the elevator shaft, so that the relative centres of the shaft are maintained, irrespective of the angle of the elevator.

When in operation the elevator is pushed up to the coal heap, and the coal trimmed forward to the buckets.

Band Conveyors.—The three most important considerations in the design and construction of a band conveyor are (1) the quality of the band, (2) the means by which it is carried, and (3) the feed to the band.

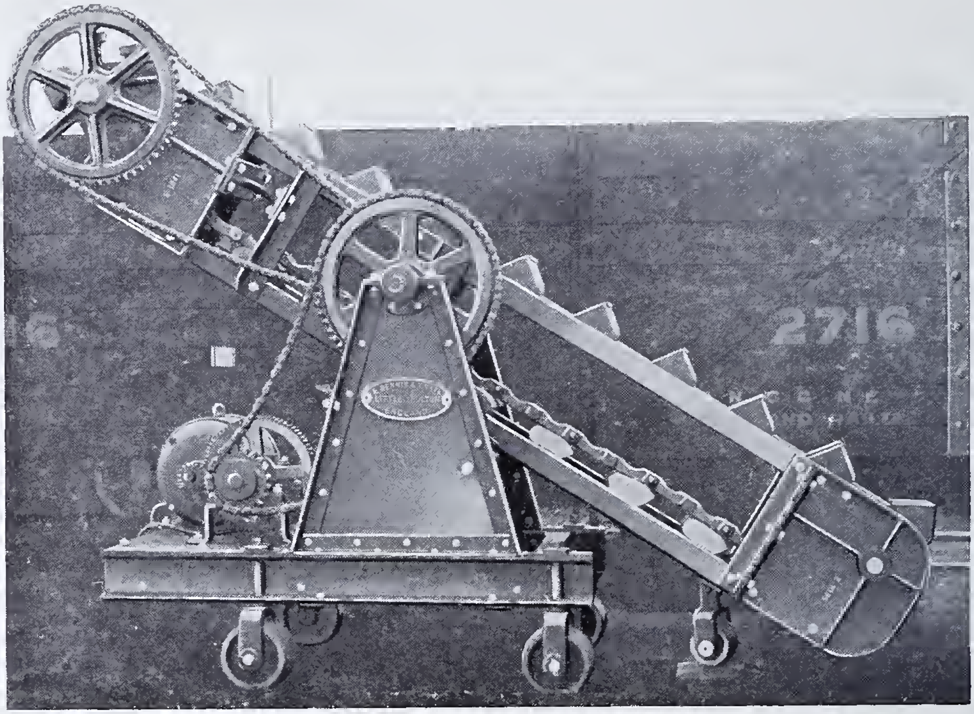


FIG. 171.—THE BENNIS PORTABLE BUCKET ELEVATOR.

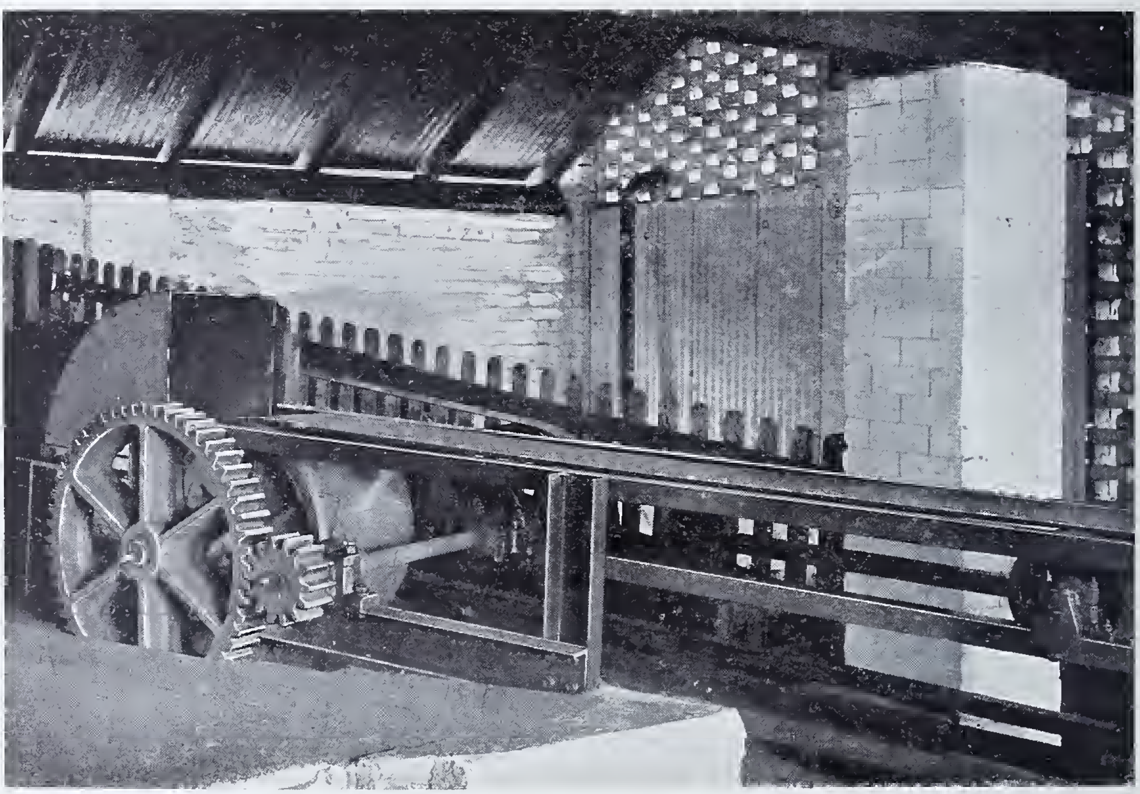


FIG. 172.—THE BENNIS BAND CONVEYOR.

Special attention must be given to the provision for the delivery of fuel to and from the conveyor. Faulty loading and distribution will both materially reduce the working efficiency, and also the life of the band.

The band conveyor illustrated in Fig. 172 is of the Bennis type, for which it is claimed that there is no cross breaking in the fibre, as the band runs flat on both the top and bottom lengths, instead of being turned up at the sides to form a trough. The securing supports are so arranged that coal is not thrown off on either side of the band between the terminals.

The idlers are of special construction and are lighter than those usually employed, ensuring that there is no slip between the idler and the band. They

Fig. 173.—The Bennis Ram Wagon Tipper.

are made of large diameter, flat on the face, balanced, and fitted with well-lubricated bearings, the friction between the idlers and the band being reduced to the minimum.

The band may be arranged to deliver at any fixed point of travel by means of throw-off carriages, or adjustable cut-offs.

Pneumatic Coal Handling.—The pneumatic handling of coal is likely to be considerably developed within the next few years. It is a system which possesses many advantages and may be employed in cases where the provision of mechanical elevators is very difficult, if not impossible. The most important plants of this type installed up to the present are at the Bankside Generating Station of the City of

London Electric Lighting Co., Ltd., and at the Brimsdown Power Station of the North Metropolitan Electric Power Supply Company.

Both of these installations were designed by Messrs Henry Simon, Ltd., Manchester, the former having a capacity of 60 tons per hour and the latter a capacity of 50 tons per hour.

The Ram Wagon Tipper.—The Bennis ram wagon tipper, illustrated in Fig. 173, is designed to empty standard end discharging coal wagons. The tipper consists of a massive ram, on one end of which a crutch is fixed, which engages the rear axle of the wagon.

The ram is raised and lowered by a screw thread. A similar thread is cut in

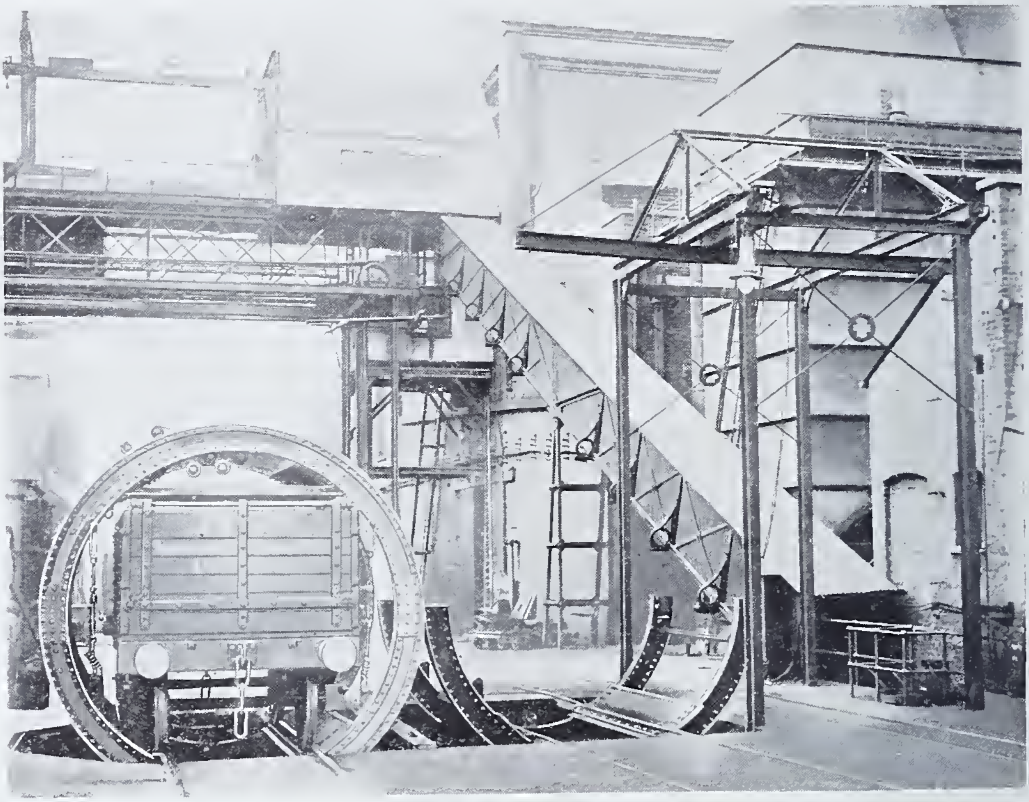


Fig. 174.—The Bennis Wagon Tippler.

the hole of a phosphor bronze worm wheel, which is turned by a mild steel worm operated through spur reduction gear from an electric motor.

The worm wheel and worm are contained in an oil bath which oscillates on trunnion bearings. The purpose of this oscillation is to allow the top of the ram to move sideways and follow the path of the wagon axle as it rises. The front wheels of the wagon, which do not leave the track, can be chocked in position. The ram is berthed in a vertical position in a pit beneath the ground.

About 5 B.H.P. is required to raise a full 10-ton wagon; the tipper may, if desired, be arranged for a belt drive from adjacent shafting, if electric power is not available.

The Bennis Rotary Wagon Tippler.—This rotary tippler is specially designed for emptying coal wagons at the rate of from 60 to 100 tons per hour. The loaded wagon is turned over bodily, the contents being deposited into an underground bunker, passing thence to a conveyor.

The centre of gravity of the loaded wagon is approximately at the centre of the tippler rings. Balance weights are fixed at the top of the tippler rings to counteract the weight of the frame and the empty wagon. By a complete revolution of the tippler trimming is rendered unnecessary, the wagon being expeditiously and completely emptied. The tippler, which is illustrated in Fig. 174, is built to handle 10, 15, or 20 ton wagons.

Coal Measurement.—The best appliance yet devised for the continuous and automatic measurement of coal used with chain grate and travelling grate mechanical stokers is the Lea coal meter.

The Lea Coal Meter.—This apparatus operates upon somewhat similar lines to the well-known V notch recorders and integrators for water measurement. Its action is based upon the theory that when coal is supplied to a boiler by means of a travelling grate stoker the amount of fuel passing under the fire door may be regarded as a stream with a constant width, but the depth and velocity of the stream are subject to variation.

The width of the stream is the width of the grate, the depth is the thickness of the fire, and the speed is the rate of travel of the grate, therefore :—

If W=the width of the stream in feet.
T=the thickness or depth in feet.
V=the velocity of the stream in feet per hour.

Then the cubic feet per hour
$=W \times T \times X$
$=$cross sectional area $\times V$.

Although slack and small coal are not perfectly homogeneous and do not obey the laws of fluids, it has been found by experience that under ordinary conditions of working the flow of coal under a fire door is, generally speaking, proportional to the thickness of the fire, and to the velocity of the grate, and that the results are very consistent with what might be expected theoretically.

As the width W is constant and T and V are the only variables, it will be seen that all that is required is some form of automatic integrating mechanism, which will at all times take into account the two items T and V. This is what the inventors claim that the Lea coal meter does.

From the diagram Fig. 175 it will be noted that the velocity or movement of the grate is transmitted by gearing to a spirally toothed drum whose pitch is equal (or proportionate) to the maximum lift of the fire door, the height of which determines the thickness of the fire H. A toothed counting wheel gearing, with the spiral drum below and a counting box above, is mounted upon a rod or drawbar directly connected with the fire door; as the fire door is opened and closed the

counting wheel is moved to and fro laterally across the spiral drum which revolves it more or less according to its lateral position.

Assuming an 8-inch fire to be the maximum—

With an 8-inch fire the counting wheel will engage with all the teeth in the drum.

With a 4-inch fire the counting wheel will engage with half the teeth in the drum.

With the fire door closed the counting wheel will not engage at all.

If the speed of the grate were doubled the speed of the counting wheel would also be doubled. If the grate were stopped entirely, the counting wheel would also stop. For all variations, either in the thickness of the fire or in the speed of the grate, the total number of revolutions of the counting wheel will be proportional to the total cubic feet of coal passed, and by means of proper constants or figures for the units shown on the counting dial, the total quantity either in cubic feet, tons or pounds can easily be determined.

It will be observed that the actual quantity of fuel passing is recorded in units.

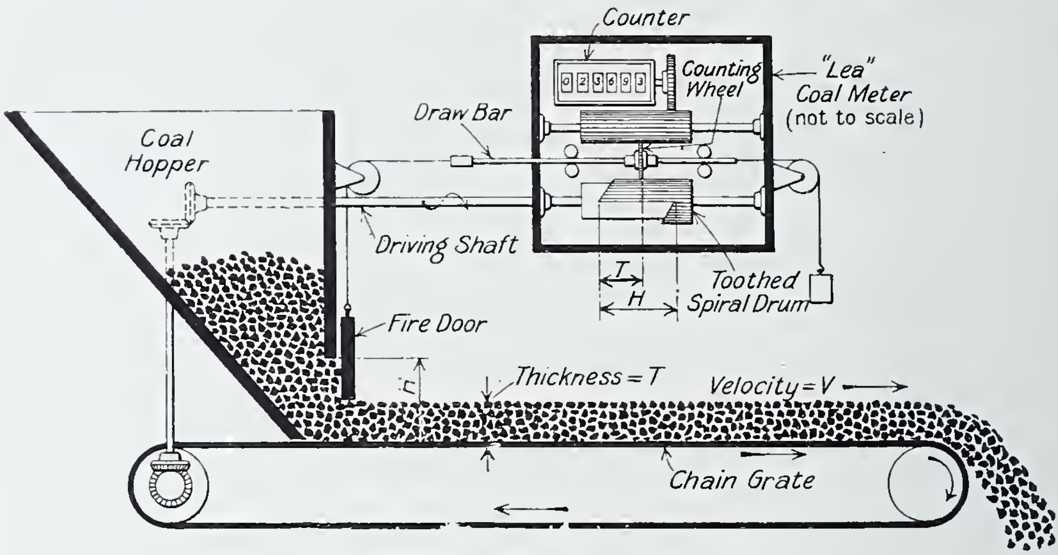


Fig. 175.—The Lea Coal Meter.

In each case the unit must be determined by the user. This can be done by measuring out on the stokehole floor a certain number of cubic feet of coal (the greater the number the better), passing this through the stoker and noting the number of units recorded by the meter. Accuracy is guaranteed by the makers within a limit of $2\frac{1}{2}$ per cent.

The Lea coal meter is illustrated in Figs. 175 and 176.

Ash and Clinker Handling.—The removal of ash and clinker is a problem which within the past few years has become much more pressing. The increased percentage of incombustible and the high cost of labour, to say nothing of the cost of ultimate disposal, and the desirability of improving boiler-house conditions, are all factors which emphasise the necessity for introducing improved methods of handling residual waste.

In connection with all steam plants having a coal consumption of 50 tons

and upwards per week, it is well worth while to consider the installation of simple automatic plant specially designed for rapid and economical removal of incombustible.

As already observed in a previous chapter, the problem of ash and clinker removal may be and is to a large extent overcome in connection with machine fired boilers of the water tube type. With all other types of boilers, however, it is impossible to employ similar means, and the incombustible must be handled manually to the extent of bringing the same to the front of the boilers, even if means are there provided for its automatic removal.

In connection with many of the larger boiler installations, ash elevators and conveyors are in use; to a large extent these have adequately met individual requirements, and have very considerably reduced the labour cost.

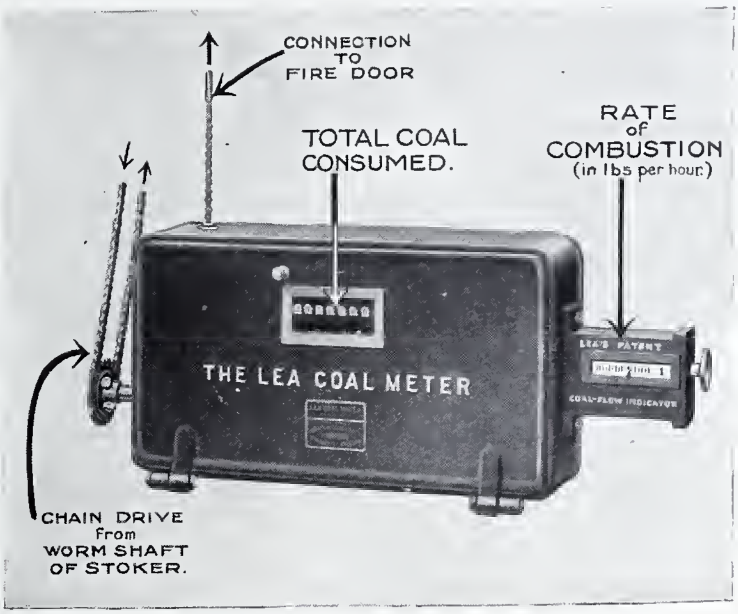


Fig. 176.—The Lea Coal Meter.

Pneumatic and Steam Suction Systems.—In some respects the modern pneumatic or suction ash handling plant is preferable to mechanical handling, inasmuch as it not only possesses the merit of simplicity, but while removing ash and clinker it may also be arranged to remove soot and flue dust.

Two types of such plant are made by Messrs E. Bennis & Co. Ltd., one of which is known as the pneumatic ash plant, the other as the steam suction ash conveyor. Fig. 177 illustrates a typical lay-out of a Bennis ash and soot handling plant, comprising a motor driven rotary exhauster, foul air cleaner, ash tanks, and the necessary pipe lines for conveying the ash or other material to the tanks.

Holes are provided in the floor plates in front of each boiler, each hole being fitted with a dumping hopper, grid, and air cut-off. As the ash is drawn

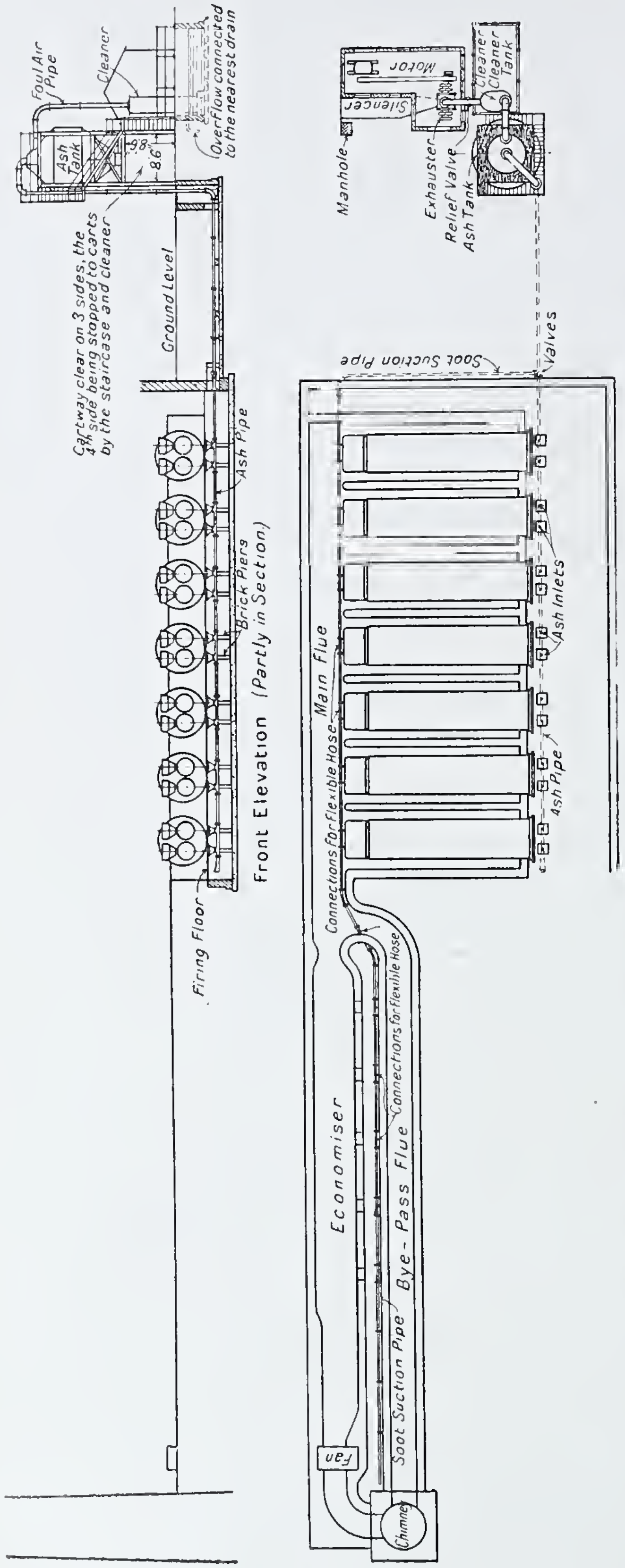


FIG. 177.—GENERAL ARRANGEMENT OF COMPLETE BENNIS PNEUMATIC ASH REMOVAL PLANT.

from the cleaning chambers at the back of the mechanical stoker grates it is dumped through these openings direct into the ash pipe, see Fig. 178, thence being carried by suction into the ash tank.

The pipes used for conveying the ash are of hard cast iron with flanged ends and copper asbestos joints, the pipes being carried upon brick piers, built into or at the side of the blow-off trench. At points in the pipe line where there is a change in direction special bends are used, the wearing parts of which are of hard chilled iron, and renewable.

In order to provide for the removal of any obstruction at the bends, a handhole with an air-tight door is provided at each end of all bends.

The ash tanks are provided with discharge valves and water sprays, the latter being arranged inside the coned portion of the tank, a pipe being taken from the lower portion into a sump for the disposal of any accumulation of excess water. This pipe is water-sealed in the sump.

A pipe of larger diameter than that used for the ash is connected to the upper portion of the tank, and through it the foul air passes to a water-sealed cleaner or scrubber. This apparatus consists of a water-sealed vessel fitted with rows of water sprayed bafflers, to intercept dust or fine particles of ash, which otherwise might be carried into

the exhauster. The large water seal at the base of the cleaner acts as a safety valve in case of undue pressure or vacuum in the apparatus.

The ash is discharged from the tank by means of a balanced discharge valve, which permits of any required quantity being delivered direct into a railway wagon or other vehicle underneath. The discharge valve is operated by means of a hand wheel.

The pipe line for removing the flue dust from the flues, economiser and chimney base is entirely separate from the ash pipe line, but as a rule the pipe lines are connected at the foot of the pipe line leading to the ash tank.

The flue dust pipes are laid in the cleaning out pit alongside the economiser, and are fitted with various connections in the length of the main flue and at the entrance to the chimney. The remaining sections of the pipe are usually carried in trenches below the ground level. Flue dust is removed from the flues and economiser chambers through short flexible pipes which are removable, and may be fixed to whichever branch it is desired to use. Cover plates are provided for the flues and economiser for closing down when the dust is being removed. The suction end of each flexible pipe is fitted with a special type of unchokeable nozzle.

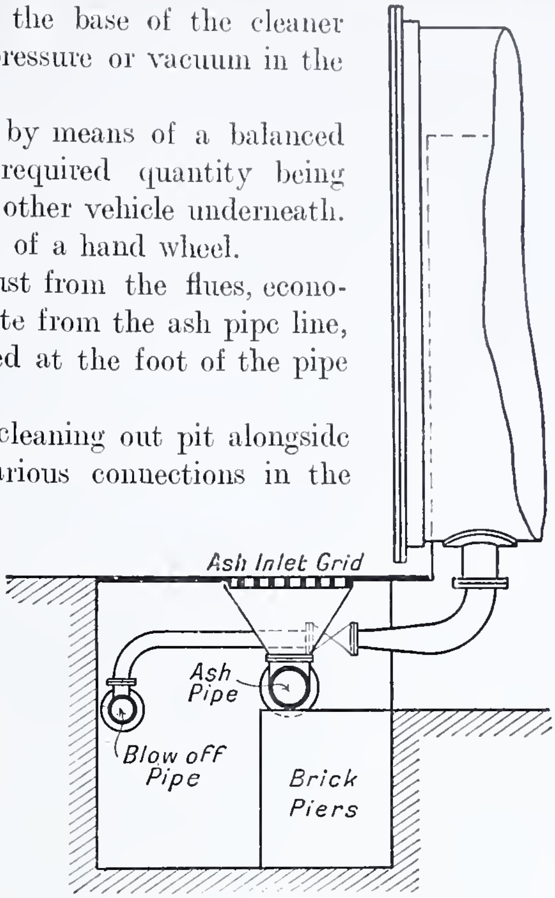


FIG. 178.—THE BENNIS PNEUMATIC ASH REMOVAL PLANT, ASH INTAKE.

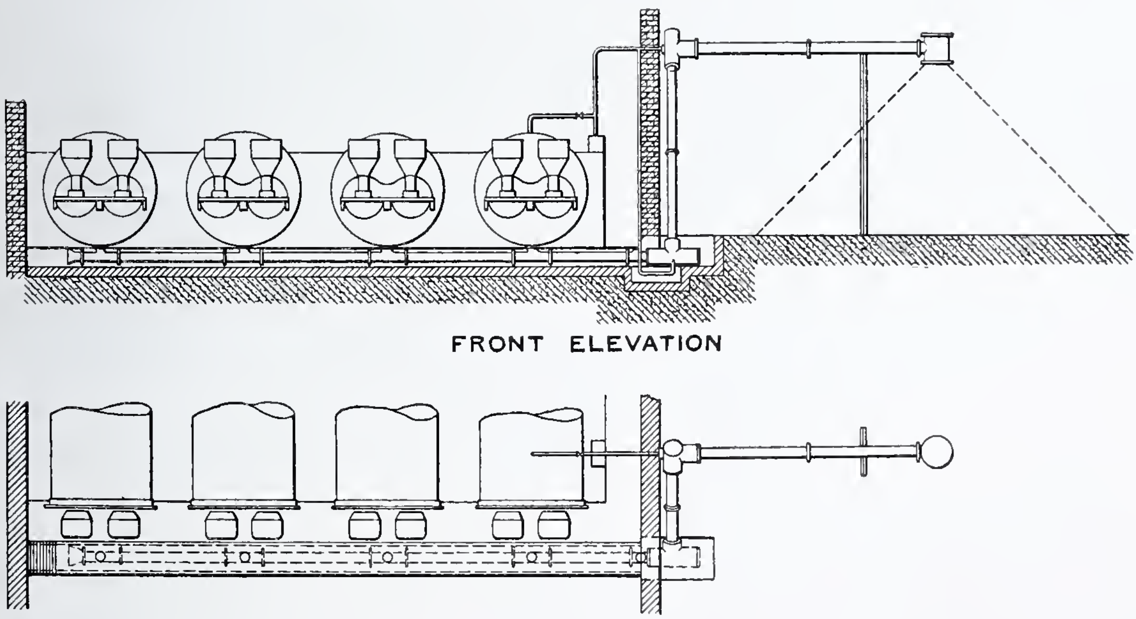


FIG. 179.—THE BENNIS STEAM SUCTION ASH CONVEYOR, AS ARRANGED TO DISCHARGE ON A HEAP OUTSIDE THE BOILER HOUSE.

The motor driven exhauster is of the rotary blower type, varying in capacity according to the quantity of residual to be handled.

The Steam Suction Conveyor.—For small boiler houses, where the cost of a

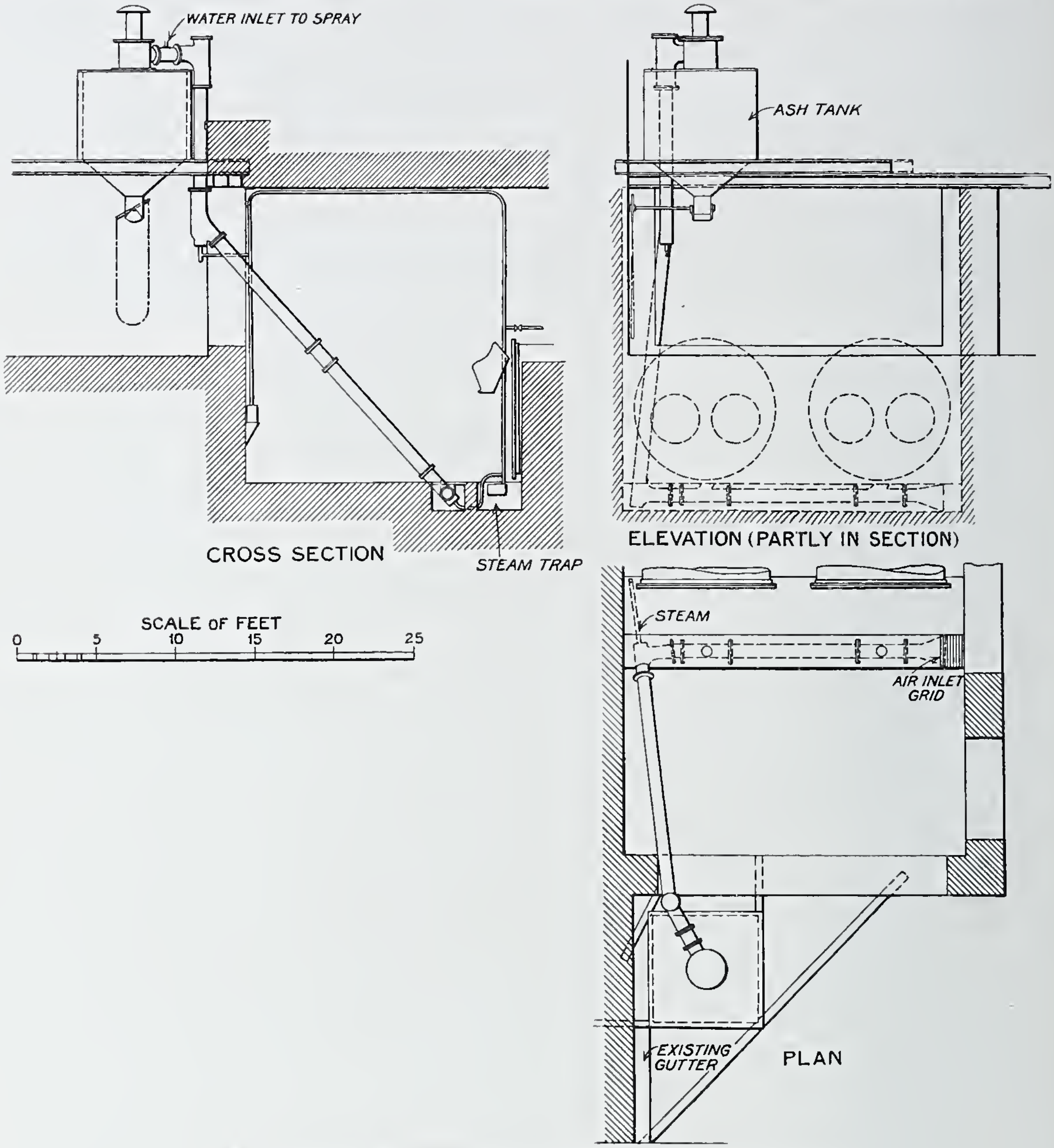


Fig. 180.—The Bennis Steam Suction Ash Conveyor.

pneumatic system is not warranted, a simple form of steam suction conveyor is very useful. This type is illustrated in Figs. 179 and 180.

The steam suction ash conveyor comprises a heavy cast-iron pipe line fitted as may be necessary with bends, tees and corner pieces, which have renewable chilled metal wearing parts.

For the removal of ash a pipe line is laid in the boiler house, usually under the

floor plates, ash intakes being provided in the floor in front of the boilers. The diameter of the pipe line is usually 6 in. to 8 in., the latter being preferable as it will take the larger pieces of clinker. The holes in the pipe line are provided with valves through which the ash is raked into the pipe.

Economisers and flues are similarly cleaned, branch lines of smaller diameter —usually 4 ins.—being used for this purpose.

When the steam valve is opened the ash is raked into the intake of the conveyor

FIG. 181.—THE BENNIS BUCKET ASH ELEVATOR.

and carried, by means of the suction created to the overhead ash hopper, to an ash heap outside, or direct into a railway wagon or other vehicle. With this system ash can be elevated or carried for distances of from 200 to 300 ft. if so desired.

Bucket Ash Elevators.—The bucket type of ash elevator with covered overhead storage bunker is illustrated in Fig. 181. This type of elevator has been extensively used in connection with many small boiler installations.

In the case of the plant illustrated, the ash is dumped into an 8-in. bucket elevator, arranged in a corner of the boiler house, and is carried by the elevator

into an overhead bunker, having a capacity of 10 tons. The bunker discharge outlet is controlled from the ground level by means of a hand lever and rotary cut-off valve.

The Usco Ash Conveyor.—The Usco ash conveyor may be described as a scraper or drag type of conveyor working in a trough arranged immediately below

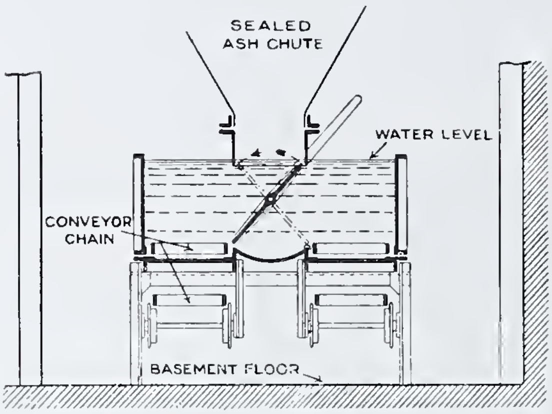


FIG. 182.—THE USCO ASH CONVEYOR, STANDARD ARRANGEMENT.

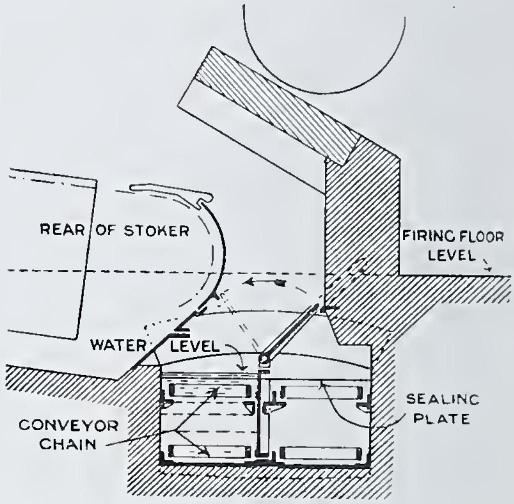


FIG. 183.—THE USCO ASH CONVEYOR AS ARRANGED IN A BOILER SETTING.

that part of the furnace where the ash is delivered; in the case of a travelling grate stoker, under the rear end. The ashes are delivered from the stoker into a chute, the end of which is below the level of the water with which the trough is filled, and in which the conveyor operates.

The standard method of installing the system is shown in Fig. 182, where two conveyor chains are working in one trough, with a hinged door between them, serving to divert the flow of ashes coming through the chute on to one or other chain, whichever may be in operation at the time. The trough is designed so that either chain can be removed from it without dismantling any other part of the gear.

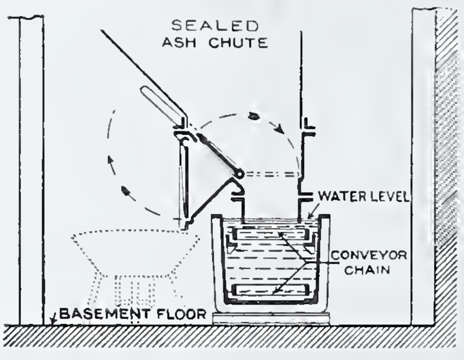


FIG. 184.—THE USCO ASH CONVEYOR, SINGLE TYPE.

The trough is usually a cast-iron vessel built of strong ribbed plates running the whole length of the boiler house, and about 2 feet high. It may be supported upon trestles from the basement, as shown in Fig. 182, in which case the return part of the chain will usually run on rollers underneath the trough. In the case of boilers which are built on the ground level, or under which no basement or ash tunnel exists, the trough may be built in the boiler setting as shown in Fig. 183. In small installations, where the cost of a duplicate conveyor may not be warranted, a single conveyor may be provided as

shown in Fig. 184, with an alternative outlet on the chute, so that the ashes may, if so desired, be discharged on to the floor of the tunnel, to be removed by other means.

The methods shown in Figs. 182 and 183 necessitate that the ash and clinker pass through the return chain on to the lower or operative part of the chain, the space between the chains and the cross bars being ample for the largest pieces to pass.

The ends of the trough are inclined upward so that it may contain water which is of sufficient height to seal the ends of the ash chutes. The ashes are thus quenched as they fall from the furnace, preventing the escape of dust and fumes.

Fig. 185.—The Usco Ash Conveyor and Ash Hopper in Tunnel with Alternative Discharge into Tip Wagon.

The delivery end of the conveyor may be continued any distance required, so that the ashes be discharged into a bunker or railway wagon, or on to a dump. The ash chute is only intended for allowing the clinker to drop from the furnace into the trough, and must not be considered as a storage hopper.

The illustration Fig. 185 is reproduced from a photograph showing the conveyor with ash hopper in an ash tunnel.

The outlet at the base is usually about 18 in. wide and 3 to 4 ft. long in the length of the trough, so that the largest clinker can readily pass. The Usco conveyor is made by The Underfeed Stoker Co., Ltd.

Soot Removal.—With the continued increase in the size of water tube boiler units, the necessity for adopting improved methods of soot removal has become increasingly acute.

It is scarcely necessary to observe that the loss of heat conductivity is serious as the result of the constant deposit of soot upon the heating surface of the boiler.

The Soot Lance.—The soot removing apparatus which has been commonly used for many years past, and which is still mostly employed, is known as the steam or sooting lance, of which it may be said that its only virtue is its simplicity.

This method of removing soot has always been regarded as expensive and inefficient, while at the best being but a clumsy expedient. To a large extent it

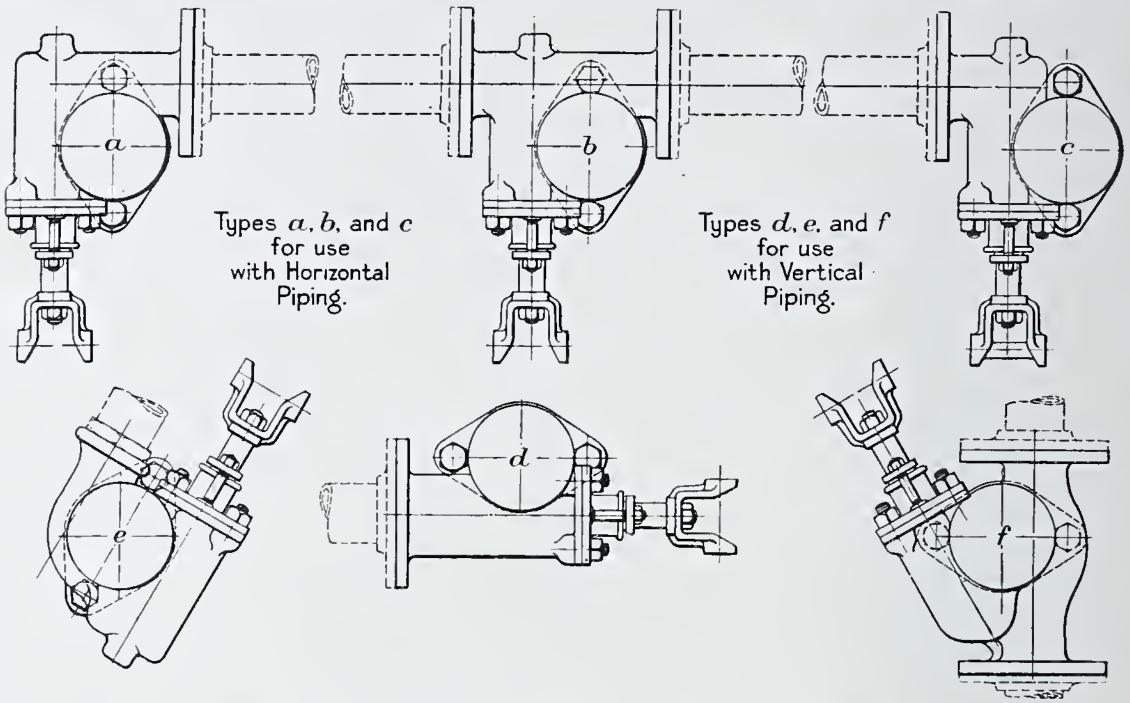


Fig. 186.—Applications of the Diamond Soot Blower.

has failed to effectually remove soot; it might, in fact, be more fairly described as a soot disturber.

In practice too large a proportion of the soot is merely lifted from one section of the boiler and deposited in another; in short, the method is haphazard, and as such must ere long be superseded by a positive and efficient system.

Mechanical Soot Blowers.—In the larger installations of water tube boilers, hand sooting is now being abandoned in favour of mechanical soot blowers. The adoption of larger boiler units, and accordingly the greater width between the side walls of the setting, renders imperative the adoption of some simple and effective means of ridding the heating surfaces of soot deposit.

In the United States for some few years past the use of the steam lance has been largely abandoned in favour of fixed mechanical soot blowers, operated as a general rule from the firing floor and used at frequent intervals.

Diamond Soot Blowers.—The diamond soot blowers illustrated in Figs. 186 and 187 are bolted upon the side or sides of the boilers in suitable positions, having in mind the working range of each blower. The blower jet tube has a line of jets along its length, the jets lying at right angles to the boiler tubes.

The operating head of the blower contains a dual purpose worm gear, the first movement of which by means of the extension handle on the blower opens the valve which is contained in the steam head, the further movement giving motion to the jet tube, and rotating the same through the segment of a circle, thereby subjecting the tubes to the cleaning action of the steam jets as they traverse through the paths indicated. The limit of travel is fixed by stops fitted in the blower head.

The operation of the blowers is very simple, no skilled attendance is necessary. The advantage of the valve in the head is not only in simplifying the pipework, but the design admits of instant movement of the jet tube as soon as the steam supply is fully opened.

The ideal cleaning action with a soot blower is in the slow and steady action of the jet tube, as it will be readily understood that only a slight movement of the same will cause the jet at its extremity to pass over a considerable distance. The worm drive in the head ensures this action.

It is claimed that the simplicity and ease with which the blowers can be operated encourage their regular use, whereas there is no doubt that sooting with a lance is work which is as unpopular as it is ineffective.

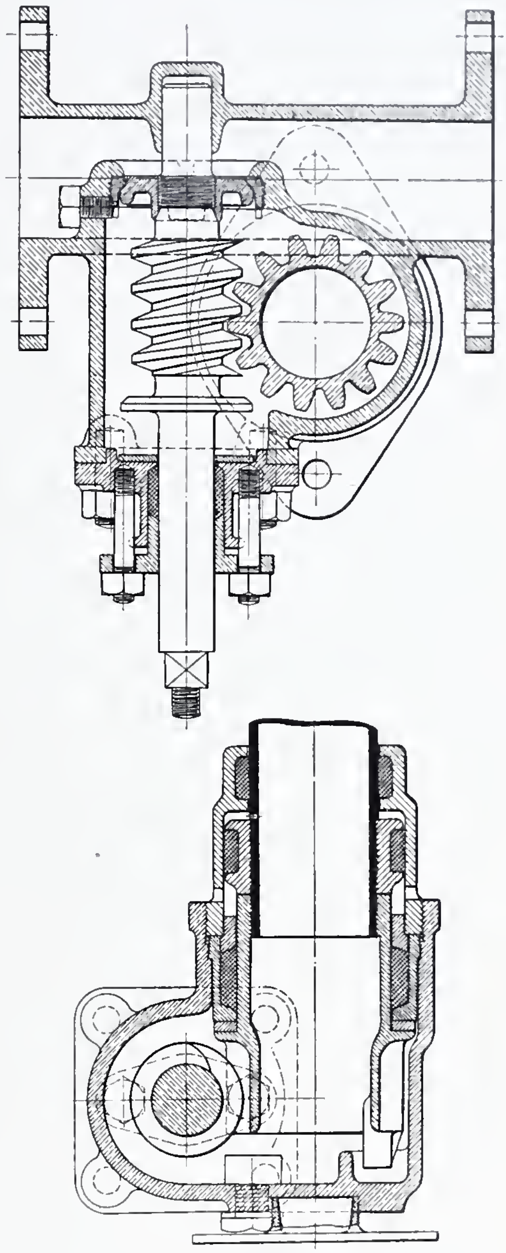


Fig. 187.—The Diamond Soot Blower.

The blower jet tubes are constructed of Perek's reactal metal, which is said to be capable of standing constant exposure to a temperature of 1000° C., and to be unaffected by chemical action of the furnace gases.

The blowers may be operated either from the firing floor level or from a gantry as desired. As compared with the operation of the steam lance, the blowers provide a positive method; they eliminate the uncertain and variable human factor, un-

doubtedly doing the work very much more efficiently and quickly, with a reduction in the consumption of steam used.

Further, the systematic and frequent use of apparatus for freeing the heating surfaces of soot deposit means greater heat transmission and a lower temperature of the exit gases, with a consequent increase in the thermal efficiency.

The Covering of Boilers and Steam Pipes.—In one of the excellent technical papers [1] prepared by the United States Fuel Administration for the guidance of steam users, the use of non-conducting material for the covering of boilers and steam pipes is thus referred to :—

"If you cover a steam pipe with asbestos, magnesia, or other heat-insulating material, you keep the heat in the steam. If you line or coat a boiler tube with scale or other heat-insulating material, you keep the heat out of the boiler water and send it to the stack. By lagging your pipes you save fuel easily. By lining your tubes with scale, you waste it continuously and needlessly."

Not only is the loss of fuel heavy as the result of failing to cover boilers and steam pipes with non-conducting composition, but the use of cheap, unsuitable and inefficient material is also responsible for a serious avoidable loss.

While obviously a covered surface must be more efficient than a bare surface, the use of an insufficient thickness of insulation, as also cheap composition, having an efficiency of from 40 to 60 per cent., is all too common.

The higher steam temperatures which are now becoming common practice necessitate the use of non-conducting covering, not only of proved efficiency, but also capable of withstanding constant exposure to high temperature conditions, without charring or disintegration.

The tabulated results of tests (Tables 42 to 44) showing the heat losses from covered and uncovered pipes are of unusual interest, as they have been extracted from a report on insulating materials prepared by The National Physical Laboratory, Teddington, in December 1922 and January 1923, for Messrs Hobdell Way & Co., Ltd., by whose courtesy they are included.

Instruments and Testing.—In Technical Paper No. 219,[2] prepared by the United States Fuel Administration, based upon an article by Mr Joseph W. Hays, the importance of using control instruments is thus referred to :—

"There is absolutely only one way to stop wasting coal burned in steam power plants. Part first of this one and only way is to ensure that every particle of the carbon of the coal comes into intimate contact with enough heated air to supply $2\frac{2}{3}$ lbs. of oxygen [3] to each lb. of carbon.[4]

Part second of this one and only way to ensure fuel economy is to ensure that the maximum proportion of the heat developed produces steam.

[1] See Technical Paper 218, "Boiler Water prepared by the United States Fuel Administration," in collaboration with the Bureau of Mines. Reprint of Engineering Bulletin No. 3, Department of the Interior, Washington, 1919.

[2] See Technical Paper No. 219, "Combustion and Flue Gas Analysis," Department of the Interior, Bureau of Mines, 1919.

[3] This weight of oxygen would be contained in 11·5 lbs. of air.

[4] Carbon will be considered to be the only combustible component of coal.

TABLE No. 42

Heat Loss from Covered Pipes

B.T.U.'s per hour per square foot of lagged surface per degree Fahrenheit temperature difference between the pipe and the air of the room.

Cover.	Heat loss in B.T.U.'s per hour per square foot per degree temperature difference.								
Composition.	Temperature difference.								
	180° F.	270° F.	360° F.	450° F.	540° F.	630° F.	720° F.	810° F.	108° F.
1. Magnesia, 2″ + Achilles, ½″	0·30	0·30	0·31	0·32	0·32	0·33	..	..	..
2. Hobsil, 1·2″	0·60	0·61	0·61	0·63	0·64	0·65	..	..	..
3. Hobsil, 1·2″ + Magnesia, 0·99″	0·35	0·36	0·36	0·37	0·38	0·39	0·40	0·40	..
4. Hobsil, 1·2″ + Magnesia, 0·99″ Achilles, 0·80″	0·33	0·33	0·34	0·34	0·35	0·35	0·36	0·37	0·39
5. Magnesia, 2·12″	0·27	0·28	0·29	0·30	0·32	..	..	..	..

Atmospheric temperature about 70° F.

Area of 1 ft. length of test pipe = 1·44 sq. ft.

In all cases final readings were taken only when, for a given energy consumption in the heater, the temperature excess of the pipe had attained its final steady value. The results given are taken from smooth curves through the experimental points. The actual divergence of an experimental point from this mean curve was usually less than 2° C.

TABLE No. 43

Heat Losses from Uncovered Pipes

Surface :—Oxidised.

Room temperature, about 70° F.

Temperature excess of pipe.	Heat loss from pipe (B.T.U.'s) per square foot per hour per degree Fahrenheit, temperature excess.	
180°	2·5	(2·5)[1]
270°	3·1	(3·0)[1]
360°	3·7	(3·6)[1]
450°	4·4	..
540°	5·1	..
630°	5·9	..
720°	6·9	..
810°	8·0	..

[1] "The values in brackets were obtained by experiments with 5-in. pipe previously mentioned, the other figures quoted being for a 9-in. pipe. After this surface was freshly cleaned with sandpaper, a result was obtained of 2·2 units at 180° Fahr. temperature excess."

TABLE No. 44

Heat Loss from Covered Pipes

(B.T.U.'s per hour per square foot of lagged surface per degree Fahrenheit temperature, difference between the pipe and the air of the room.)

Temperature of Pipe °F.	Heat loss in B.T.U.'s per hour per square foot per degree temperature difference.					
	Magnesia.				Hobsil ½ in. + Magnesia 1 in. + Achilles ½ in.	Hobsil 1 in. + Magnesia 1 in. + Achilles ½ in.
	1 in.	1½ in.	2 in.	2½ in.		
350	0·51	0·39	0·32	0·28	0·40	0·35
400	0·52	0·39	0·32	0·28	0·41	0·36
450	0·52	0·40	0·33	0·28	0·42	0·36
500	0·52	0·40	0·33	0·29	0·42	0·36
550	0·53	0·40	0·33	0·29	0·43	0·37
600	0·53	0·41	0·34	0·29	0·43	0·37
650	0·53	0·41	0·34	0·29	0·43	0·37
700	0·54	0·41	0·34	0·30	0·44	0·38
750	..	..	..	..	0·44	0·38
800	..	..	..	..	4·44	0·38
900	..	..	..	..	0·45	0·39
1000	..	..	..	..	0·45	0·39
1050	..	..	..	..	0·45	0·39

To do both these things is absolutely the only way to make each lb. of coal generate all the steam it can.[1] *To even attempt to do either without the use of the control instruments to be referred to later, is simply to waste coal, inevitably, invariably, and unnecessarily.* In order to save fuel by burning it correctly, it is not enough to merely bring about the proper conditions in the furnace. These conditions after they are started must be kept going, and we must have some means of knowing positively that they are being kept up."

The present position in this country is that in the majority of boiler houses no provision whatever exists for the weighing of coal and the measurement or weighing of feed water.

It is scarcely necessary to observe that these are but the necessary preliminary steps towards efficiency in operation, and until means have been provided for accurately determining the weight of coal burned and the quantity of water evaporated in a given time, nothing whatever can be known as to the actual results which are being obtained.

[1] Practically, the highest desirable temperature will depend upon the fusing point of the ash.

This, unfortunately, is the present condition in connection with the majority of steam boiler installations in Great Britain. It is the root cause of the existing low average thermal efficiency, and is responsible for an enormous waste of coal, which is detrimental alike to the steam user and the nation.

The actual cost of weighing coal and measuring water is negligible in comparison with the value of the information obtained. The first steps towards efficiency do not involve the provision of elaborate and costly apparatus.

For occasional or periodical evaporative tests tanks may be used, and although it has been recommended that all water used should be weighed, it is usually found to be much more convenient to arrange for measurement by volume.

The most suitable arrangement is to provide two graduated measuring tanks of equal capacity, placed side by side and connected up as shown in Fig. 188, the outlet from each tank to the feed pump being provided with a cock so that the pump may take the supply of feed water from each tank alternately.

These two tanks should each have a capacity of not less than twenty minutes' supply, so that the attendant may have ample time to open and close the cocks, observe and check the water level, take the temperatures, and note all records.

It is sometimes preferred to provide a third tank to be used as a feed tank, this being fed alternately with fixed and equal quantities by the two calibrated tanks, the pump or injector taking its supply from the feed tank. As a general rule it will be found that the arrangement of two tanks is perfectly satisfactory, but there is, of course, no objection to the provision of the extra and separate feed tank, if so desired.

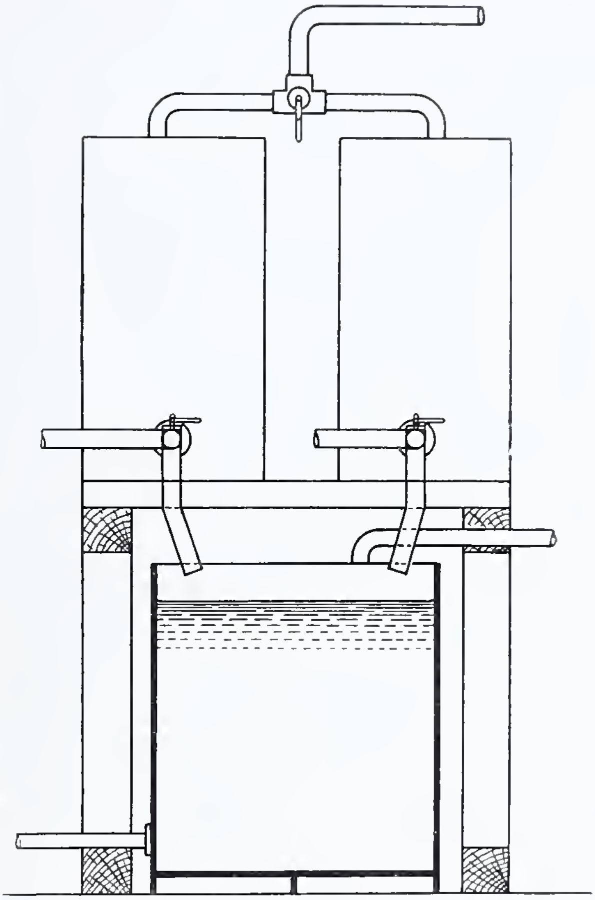


Fig. 188.—Arrangement of Feed-water Measuring Tanks.

With careful and systematic operation this method of water measurement is accurate, and will meet all reasonable requirements, for a steam boiler plant of small or moderate size, for an occasional evaporative test, and also for the checking of meter measurement.

All coal must be weighed, and as with the water so with the coal, absolute accuracy in the records taken is essential. For an ordinary test it will usually be found quite satisfactory to weigh the coal in a barrow or other receptacle on a scale or weighing machine, in quantities of 1 cwt. or 2 cwts. at a time. In order, however,

to avoid the constant weighing of coal throughout the test, it is best to arrange at intervals to weigh half a ton or one ton, then depositing the same upon the firing floor ready for use.

For periodical evaporative tests, the proposed arrangements both in regard to the measurement of feed water, and the weighing of coal will be found quite satisfactory, while not involving either serious trouble or expense.

For the continuous measurement of feed water, either of the meters already described may be used or others. For the constant automatic measurement and recording of coal used in connection with individual boilers, the Lea coal flow meter, see Figs. 175 and 176 will be found exceedingly useful, although the application of this device is limited to water tube boilers, fitted with chain grate, or travelling grate stokers.

There are other types of continuous weighing and measuring apparatus for coal used in connection with overhead bunkers, and a gravity supply through coal chutes, delivering the fuel into the hoppers of mechanical stokers ; these are made both in fixed and travelling types.

Assuming that means are provided for the satisfactory measurement or weighing of the feed water, and the coal, either for periodical or continuous use, it is then necessary to provide for analysis of the fuel used.

In the case of works of small or moderate size, where the conditions are such that a reasonable efficiency can be maintained with occasional evaporative tests, it is not necessary to provide for the analysis of fuel on the premises. Carefully selected samples may be taken periodically, and sent to one of the well-known testing laboratories for their report.

Having arranged for the measurement of weighing of coal and feed water, as also for the analysis of coal, it is now possible to ascertain what is being done, *i.e.* what results are being obtained, and to compare the same with the results which *should* be obtained, having in mind the calorific value of the fuel used.

In the average case it will be found that the evaporation obtained per pound of fuel burned is low, in many cases very low. It may, for instance, be shown that by comparison with the calorific value of the fuel used, that only from 50 to 60 per cent. of the heat units in the coal are accounted for in the evaporative results obtained.

The next step towards efficiency is to discover how, why and where, the loss in efficiency may be accounted for. This involves the provision and careful use of instruments, and apparatus, which will be discussed, as also the systematic logging and study of all essential records.

The range and types of the instruments to be used will necessarily be determined by the size of the steam plant. While it is impossible to secure and maintain efficient working conditions without the use of certain apparatus, such as a draught gauge, a CO_2 recorder, or flue gas analyser, a pyrometer, and thermometers, the type and number of these and other instruments, and a cordingly their cost, will depend upon the number of boilers used, and the choice between a rigid system

of testing, recording, and checking, or with small plant periodical testing and checking only.

In large works where a spare boiler is available it is desirable to completely equip a boiler for continuous testing and experimental purposes. It is then possible to carry out very exhaustive, practical tests, under working conditions, and to determine and set the efficiency standard for all the boilers.

Even for small works, as already observed, a certain definite minimum equipment is necessary, if any effective steps are to be taken to determine the existing conditions, and to bring about any material improvement.

Coal Analysis.—The analysis of coal is of vital importance, not only in order to determine the results which *should* be obtained in its combustion, but also to ascertain its quality, characteristics, and suitability, as also its comparative value, having in mind its cost.

In order to take any really effective steps for the promotion of economy and efficiency in the boiler house, it is of primary importance to institute a regular system of fuel analysis.

If fuel analysis were the general rule among steam users, if the vast majority, instead of the comparatively few, adopted this course, the coal owner and the middleman would very quickly realise that existing methods must cease, and that the purchaser must be supplied with a commodity closely approximating in value to the price demanded.

If steam users generally thus took steps to protect themselves, far less would be heard about dirty coal, and also excessive moisture in some fuels. Under existing conditions steam users have had to pay very heavily for useless incombustible, and also water. While it is true that cleaner fuel is now being supplied, the user will not be adequately protected until he protects himself, and he will not reach this stage until he realises the importance of analysis.

In the United States, it is now possible to purchase fuel on the basis of its calorific or heat value, which is the only correct and satisfactory purchase basis.

This is the purchase basis which must ultimately be adopted in Great Britain, although hitherto it has not found much favour. A much more extensive adoption of fuel analysis by steam users would undoubtedly tend towards this desirable change in the purchase basis, and hasten its general recognition and adoption.

Referring to the purchase of coal, Mr R. Clayton in his very useful work, "Boiler Inspection and Maintenance,"[1] makes the following observations :—

"In the past coal has generally been purchased in a slipshod manner—usually in the cheapest market—and it has been used without any systematic reference to its quality, or to the amount of work which it performed. Whilst large coal bills were deplored, no attempt was generally made to investigate the reason.

"In the majority of factories no idea prevailed as to the amount of steam raised per day, or per working week, and coal delivery notes were usually strung on a

[1] See "Boiler Inspection and Maintenance," by R. Clayton, Surveyor, Manchester Steam Users' Association.

skewer and hung in some odd corner of the general office, to litter the place and harbour dust."

Those who have had experience of the conditions which have obtained, and which still obtain in a large number of works, will not question the accuracy of Mr Clayton's statements. These are the conditions which will have to be abandoned before any considerable advance can be made in the efficient use of coal for the generation of steam.

There is only one correct method of purchasing coal, that is on the basis of its calorific or heating value as determined by a calorimeter, due consideration being given to the quantity of moisture, both hygroscopic and free, the percentage of ash and sulphur, as also the volatile hydrocarbons.

Proximate analysis, which will suffice for all ordinary purposes, gives the moisture percentage, and the percentages of volatile matter, fixed carbon, and ash, as also the calorific value of the fuel.

Ultimate analysis, which for all ordinary purposes is quite unnecessary, gives the chemical composition of the coal, *i.e.* the percentages of carbon, hydrogen, nitrogen, and oxygen. The loss due to moisture in coal usually averages about 4 to 5 per cent., but as this loss increases at the rate of 1 per cent. for every 10 per cent. of free moisture in the fuel, it is very desirable in its purchase to have due regard for the moisture content, which in the case of coke breeze and coke, may be as high as 15 per cent. or even in excess of this.

The moisture loss referred to above is the combustion loss, this does not represent the *total* loss due to an excessive moisture content, inasmuch as the moisture is purchased at the same rate as the fuel, involving also the extra cost of transport and handling.

In proximate analysis it is understood that the term volatile matter applies to the volatile hydrocarbons liberated by heat as distinct from the moisture. The fixed carbon is the carbonaceous residue remaining after the distillation of the moisture and volatile matter, and after deducting the ash.

In the taking of samples of coal for analysis it is of the utmost importance that the sample shall be thoroughly representative of the bulk, otherwise the results obtained may be entirely misleading and worthless.

Having in mind the very small proportion of an average sample which is ultimately tested, it will be appreciated how easily an error of from 1000 to 2000 B.T.U.'s in the calorific value may be made, and how important it is that the sample for analysis should be selected with the utmost care.

Calorimeters.—One of the most reliable standard calorimeters is the oxygen bomb Mahler type of instrument. It is, however, a somewhat intricate apparatus, and frequent use is necessary in order to obtain consistent and accurate results.

For more general use the sodium peroxide electrically fired bomb calorimeter will be found a very convenient and useful apparatus. After a little experience in the use of this instrument it will usually be found that the results obtained will agree very closely with those obtained with the Mahler bomb calorimeter.

The Rosenhain Fuel Calorimeter.—This calorimeter is an improved form of

the well-known Thomson instrument, and is made by the Cambridge & Paul Instrument Co., Ltd.

The instrument comprises essentially two parts — the calorimeter vessel containing the water, and the combustion chamber in which the coal is burned. The combustion chamber is formed of a glass lamp chimney closed at the top and bottom, which are separated from the glass by rubber washers.

The plates are drawn together by means of screws on three nickel-plated brass uprights fixed to the lower plate. A ball containing a stuffing box is mounted on the upper plate, through which a tube passes containing the electric ignition device.

The upper plate also carries a tube for admitting oxygen into the combustion chamber. A wire gauze nozzle is fitted to the end of this tube to prevent the oxygen jet from breaking up the coal sample.

The combustion chamber communicates with the exterior by means of an aperture, thus permitting the products of combustion to pass from the vessel to the surrounding water. This aperture is closed by a ball valve which allows the gases to pass from the combustion chamber to the surrounding water, but prevents the water from entering the chamber. An arrangement is fitted by which the ball can be raised to allow some water to enter. This water is then forced out by the oxygen and mixed with the rest of the water, thus ensuring that the calorimeter and its contents are brought to one temperature. To prevent radiation the calorimeter vessel is enclosed in a wooden case, through openings in the side of which the progress of combustion may be watched.

The following accessories are required for the proper use of the instrument :—

(1) A convenient source of oxygen, capable of giving a sufficient pressure to force the gas through the instrument. A cylinder fitted with a reducing valve is most convenient.

(2) A coil of metal pipe through which the oxygen may be passed before entering the instrument. This should be fitted with a thermometer divided to 0·2° C., and its temperature should not vary appreciably.

(3) A measure of 1000 c.c. capacity.

(4) A good thermometer for measuring the rise of temperature of the calorimeter. This should be very sensitive, and capable of being read to 0·01° C.

(5) A 4-volt accumulator, and flexible leads to connect it to the ignition terminal.

(6) A small silica dish on which the coal stands during combustion.

(7) A coal-compressing mortar for preparing the coal samples. With this calorimeter practically perfect combustion is secured, less than ½ per cent. of the sample escaping combustion; when the combustion is properly regulated no carbon monoxide is formed.

A determination of the calorific value can be made in about half an hour. The combustion of two grammes of coal occupies about ten minutes.

No parts of the apparatus are exposed to high pressure, a small quantity of oxygen is required, and the only breakable part is the glass chimney, which can be replaced quickly for a few pence.

As the sample is burned under observation, its behaviour as regards caking

and clinkering can be seen. No stirring of the water is required: this is agitated by the gas bubbling through it. For standardising the calorimeter the makers supply small coal briquettes, the calorific value of which has been carefully determined and which is indicated on the receptacle. The water equivalent is best determined by burning in the calorimeter samples of this coal.

The calorimeter may also be used for testing the calorific value of oils, for which purpose the makers supply standardised absorption pellets. The Rosenhain calorimeter is illustrated in Fig. 189.

In the larger works fuel analysis would of course be regular, systematic, and

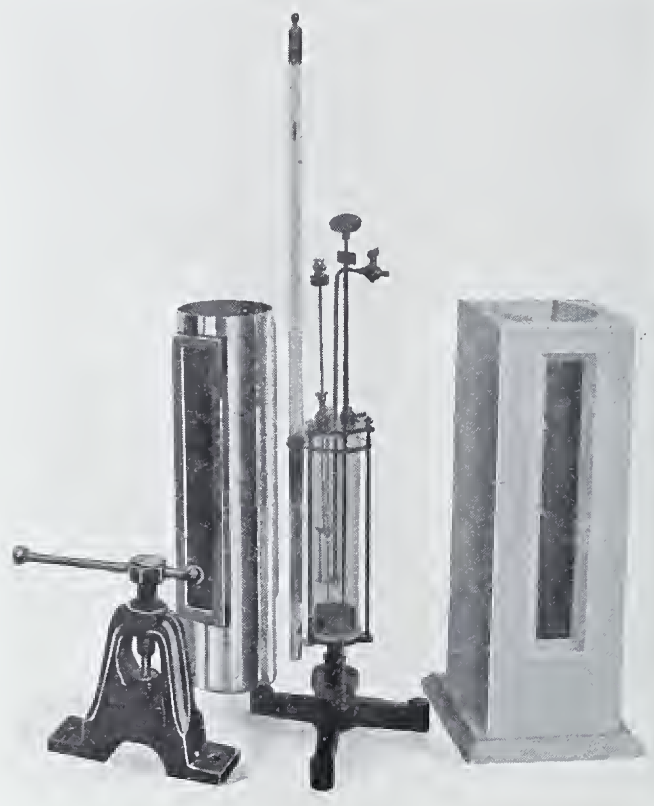


FIG. 189.—THE ROSENHAIN FUEL CALORIMETER.

actually part of the ordinary routine operation. In the case of the small works, as already observed, the analysis of coal should be no less systematic, but having in mind the less frequent deliveries with possibly no variation in the source of supply, and the small consumption, a weekly, fortnightly, or monthly analysis of a representative sample sent to a testing laboratory would serve to maintain an efficient check on the purchases, and would at the same time provide a basis for the comparison of the results obtained in periodical evaporative tests.

Flue Gas Analysis.—Flue gas analysis is essential in order to determine the completeness of the combustion of the carbon in the fuel and the extent of the heat losses due to incomplete combustion.

The quantities as determined by analysis are volumetric, and should be ascertained in the following order:—Carbon dioxide (CO_2), oxygen (O), and carbon monoxide (CO). Flue gas analysis provides data which is of much value for a study of the following:—

(1) The handling of the fire.

(*a*) Determination of the correct method of firing.
(*b*) The proper levelling of the fire to keep it free from holes and consequent air leakage.
(*c*) The depth or thickness of the fire to produce the highest efficiency.

(2) The most efficient draught for the thickness of the fire and the load on the boiler.

(3) The condition of the boiler setting from the point of view of air infiltration.

(4) The necessity for providing a secondary air supply to complete combustion.

(5) To some extent the design and construction of the furnace.

In common with all analysis the value of the flue gas analysis depends to a very large extent upon the care taken in obtaining an average sample, *and this should be taken from the body of the gas stream.*

The precise position of the sampling tube connection will be determined by the use to be made of the analysis. If it is desired to ascertain the *total* heat losses, then the connection must be made at a point where the sample will show the effect of *all* air infiltration to the setting.

If, on the contrary, data is required for furnace or fire control only, the sample must be taken at a point where the gases are not diluted by air infiltration. In every case care must be taken that no air leakage occurs around the sampling pipe, as this would give misleading data in regard to the composition of the gases.

The sampling tube preferably should be a length of $\frac{1}{8}$ in. to $\frac{1}{4}$ in. wrought-iron tube, extending into the centre of the gas stream, and arranged at right angles to its flow; the end of the tube should be cut square.

The question is frequently asked—Is continuous analysis of the gases necessary or desirable? This must be determined by the size of the plant, the working hours, and the conditions generally. For small steam plants operated for about ten hours daily under fairly regular load conditions, occasional or periodical analyses for check purposes for maintaining efficient working conditions will suffice. For all other steam plants continuous analysis with a recording instrument is not only preferable but essential, if any serious attempt is to be made to secure and maintain efficient operation and control.

In the exploitation of apparatus in Great Britain for the determination of CO_2 in the gases, there has been and still is a disposition to disregard the effect of CO. A thick fuel bed and a limited or controlled air supply will show a high CO_2 reading, but such conditions are very favourable for the production of CO, and will sometimes show an excessive quantity of CO in the gases.

The ignition temperature of CO is about 1200° F., therefore unless satisfactory diffusion is secured before the gases come into contact with the comparatively

cool heating surface, the combustion will be incomplete, despite the fact that a high percentage of CO_2 is recorded.

It is important to periodically check the results obtained from a CO_2 instrument by means of a complete gas analysis with an Orsat apparatus or a Hay's gas analyser (see Fig. 190). This check analysis will not only show whether the CO_2 instrument needs adjustment, but also if any CO is present in the gases.

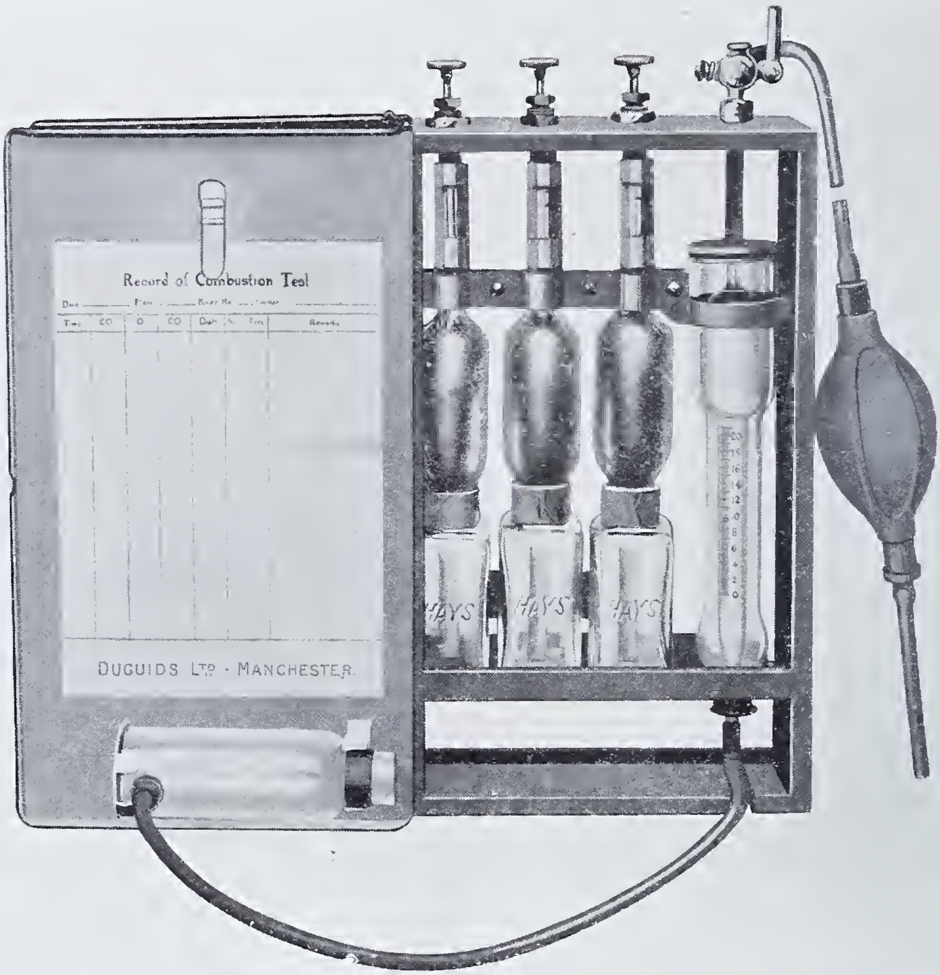


FIG. 190.—HAY'S FLUE GAS ANALYSER.

Hay's Flue Gas Analyser.—Hay's flue gas analyser, which is illustrated in Fig. 190, is of American design of the improved Orsat type, and is a very convenient and compact apparatus for the periodical determination of CO_2, CO and O.

The burette in which the gases are measured is water jacketed to control the temperature, all measurements being made at atmospheric pressure by means of the levelling bottle, which is shown attached to the base of the burette.

The instrument is provided with three absorber containers. The bulbs of two

of the containers are packed with steel wool, the bulb of the third container being packed with copper wire, while the bottle beneath the bulb contains some scrap copper. The container nearest to the burette is charged with the absorber for CO_2 (a solution of caustic potash). The middle container is for the oxygen absorber (a solution of pyrogallic acid and caustic potash), and the one containing the copper is for the carbon monoxide (CO) absorber (an ammoniacal solution of cuprous chloride).

A mixture of the gases is analysed by the volumetric method, that is, a measured volume of the mixture is taken, and one of the gases removed by absorption. The volume then remaining is measured, and the shrinkage indicates the percentage of gas absorbed.

The residual volume is then again exposed to another absorber which removes another gas. On remeasurement the volume of that gas is known. This process is repeated until all of the gases have been determined.

Under ordinary conditions it is not necessary to make the oxygen and carbon monoxide analyses, because as a general rule there is but little risk of any appreciable quantity of CO being present in the gases when the percentage of CO is less than from 14 to 15 per cent.

The first problem is to find the furnace conditions which will produce and maintain 15 per cent. of CO_2, and to actually get and maintain that percentage, or as close thereto as possible. When this has been done, it is then worth while to determine whether CO is present in the gases.

This analyser is not a difficult apparatus to operate, and if carefully used gives very accurate results, while the price is very moderate. It is sold in England by Messrs Dugids, Ltd., of Manchester.

The CO_2 Thermoscope.—The simplest and most compact hand apparatus for CO_2 determination is the thermoscope, which is made by the Underfeed Stoker Co., Ltd.

This instrument is based upon the principle that when CO_2, either pure or in admixture with air, is brought into contact with caustic soda, a chemical reaction takes place, and heat is evolved, the amount of which is proportional to the quantity of CO_2 present.

If, therefore, a measured quantity of the gas mixture to be analysed is brought into contact with caustic soda, the amount of which being somewhat more than sufficient to absorb all the CO_2 present, it is only necessary to measure the heat evolved to obtain a measure of the CO_2 in the mixture.

The thermoscope consists of three essential parts, viz. :—

(1) A cylinder fitted with a plunger for drawing a measured quantity of the gases from the flue or furnace, and subsequently passing it through ; (2) a cartridge-shaped receptacle containing pulverised caustic soda, in which the heat reaction occurs ; (3) a thermometer with its bulb constructed to surround or jacket the cartridge, so that the heat of reaction can be imparted to the mercury, the amount of its expansion, *i.e.* the percentage of CO_2 to be observed on a movable scale. For occasional use this is a very convenient portable apparatus which might with advantage be extensively employed.

The Cambridge Electrical CO_2 Indicator and Fecorder.—With this instrument, the percentage of CO_2 in the gases is determinned by an e!ectrical method which does not involve the use of any chemical absorbent. The method employed for measuring the percentage of CO_2 is one which was devised by Dr G. A. Shakespear of Birmingham University, for testing the purity of gases.

The percentage of CO_2 in the flue gases is determined by a method depending

FIG. 191.—THE CAMBRIDGE ELECTRICAL CO_2 INDICATOR.

upon the variation in the thermal conductivity of the gas, caused by the presence of varying amounts of carbon dioxide.

The instrument contains two identical spirals of platinum wire, enclosed in two separate cells in a metal block, each of the spirals being connected to form one arm of Wheatstone Bridge circuit. If an electric current is allowed to flow in this circuit, the two spirals will become heated, and will lose heat to the walls of the cells.

If the two cells contain gases of different thermal conductivity, the spirals will cool at different rates, and one will therefore be maintained at a higher temperature than the other. The difference in temperature of the two wires will cause a

deflection of the galvanometer, the extent of the deflection depending upon the difference in conductivity of the two gases.

The construction of the instrument is such that changes in the temperature of the flue gases, affect both sides of the bridge equally. If, therefore, one of the coils contains a pure gas, and the other the same gas mixed with some other constituent, the extent of the deflection will be an indication of the amount of the second gas present, and the galvanometer can be calibrated to show directly the percentage composition of the mixture. Either an indicating or a recording galvanometer may be used.

The difference in conductivity between oxygen and carbon dioxide enables the method to be employed to determine the percentage of carbon dioxide in the flue gases. These gases consist chiefly of nitrogen and carbon dioxide, mixed with small amounts of oxygen and water vapour, with perhaps a little carbon monoxide. Since carbon monoxide, oxygen, and nitrogen have all nearly the same conductivity, the small variations of the former two gases do not affect the readings, and the effect of water vapour can be counteracted by keeping the gases in both cells saturated. The difference in conductivity of the gases in the two cells will then depend only upon the percentage of carbon dioxide in the gas. This method of measurement has not yet been made suitable for determining the percentage of carbon dioxide in gases such as coke oven gas, where the percentage of hydrocarbons or other constituents vitiates the proceedings.

Fig. 192.—The Cambridge Electrical CO_2 Recorder.

The Cambridge electrical CO_2 apparatus is made in several types, comprising single or multipoint indicating or recording outfits, or combined single point or multipoint indicating and recording instruments.

For distance recording this is a very convenient apparatus. That portion through which the gases pass may be arranged close up to the flue or boiler, the indicator may be fixed in the boiler house for the guidance of the fireman, while the recording apparatus may be fixed in the office.

Figs. 191 and 192 respectively illustrate the Cambridge electrical CO_2 indicator and recorder.

The Cambridge Portab'e CO_2 and Temperature Indicator.—This exceedingly compact and portable combined indicator, illustrated in Fig. 193, embodies in a very convenient form a CO_2 indicator, identical in principle with that already described and illustrated in Figs. 191 and 192. The couple placed in the flue is connected

to the terminals marked " couple " for temperature measurements. The instrument is fitted with a multi-way switch, by means of which either temperature readings or CO_2 readings can be taken on the indicator.

Simmance's Patent S.A.W. CO_2 Recorder.—Simmance's patent CO_2 recorder made by Messrs Alexander Wright & Co., Ltd., and illustrated in Fig. 194, consists briefly of the following parts :—

(1) A gas extracting chamber working in conjunction with a syphon tank which

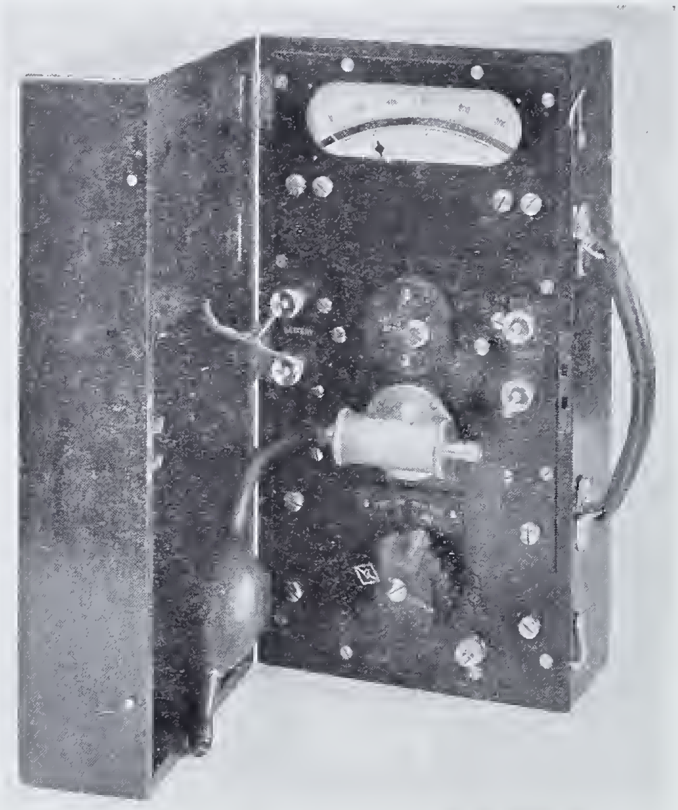


FIG. 193.—THE CAMBRIDGE PORTABLE CO_2 AND TEMPERATURE INDICATOR.

periodically extracts a large sample of gas, from which a smaller definite volume is measured off and delivered to a caustic potash tank.

(2) A potash tank fitted with inlets and outlets and a filling plug.

(3) A small gas holder with a rising bell and a scale of 100 parts for remeasuring the sample after the absorption of the CO_2.

(4) A rotating clock movement for carrying the chart and pen mechanism for recording the result of each analysis.

(5) A water cistern and injector for drawing the gas up to the recorder, and a " tell tale " gas chamber for showing the condition of the piping.

An analysis is completed about every three minutes, the ends of the pen marking on the chart form a continuous curve, showing variation in the amount of CO_2.

The Duplex Mono Automatic Gas Analyser.—This is a comparatively new apparatus made by the Svenska Aktiebolaget Mono Company of Stockholm, the special feature of which is the automatic testing and recording of CO and other combustible gases in addition to CO_2.

The working of the apparatus is dependent upon the fact that the products of the completed combustion of the carbon monoxide, and of the other combustible

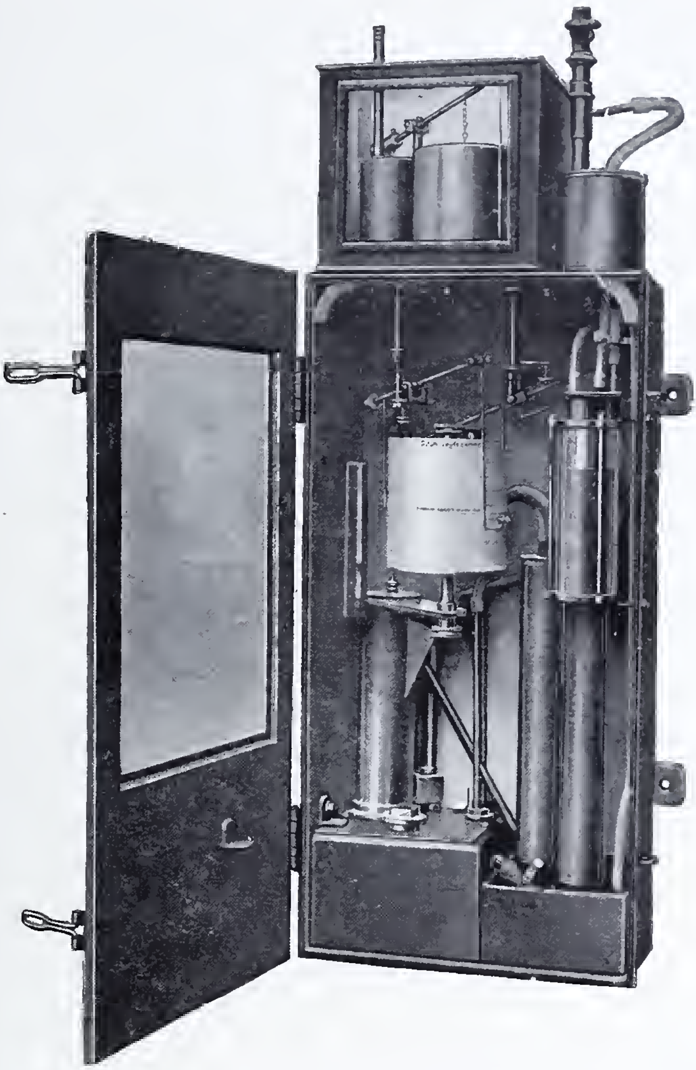


Fig. 194.—Simmance's Patent S.A.W. CO_2 Recorder.

gases, often contained in the exit gases from unsatisfactorily operated furnaces, are carbon monoxide and aqueous vapour.

If, therefore, the CO_2 be first determined in the exit gases, and subsequently after a sample of this same gas has been passed through an electrically heated tube, in the presence of a catalytic agent, and completely consumed, the difference between the first and subsequent determinations of CO_2 will indicate the percentage of combustible gas originally present in the exit gases. The aqueous vapour being condensed is removed in the course of the tests as water.

The catalyst used in the duplex mono instrument is copper oxide. The heating element used consists of an electric oven arranged on top of the measuring and absorption apparatus, provided with a quartz heating tube, filled with copper oxide. About 30 watts are necessary in order to give the temperature required in this tube.

Mercury is used in the gas switch which controls the inlet of the gas to the heater, as also its exit, no moving parts are used to force the gas through the apparatus, mercury being used for this purpose also.

The W.R. CO_2 Indicator.—The W.R. CO_2 indicator, which is of British design and make, is probably at the present time more extensively used than any other

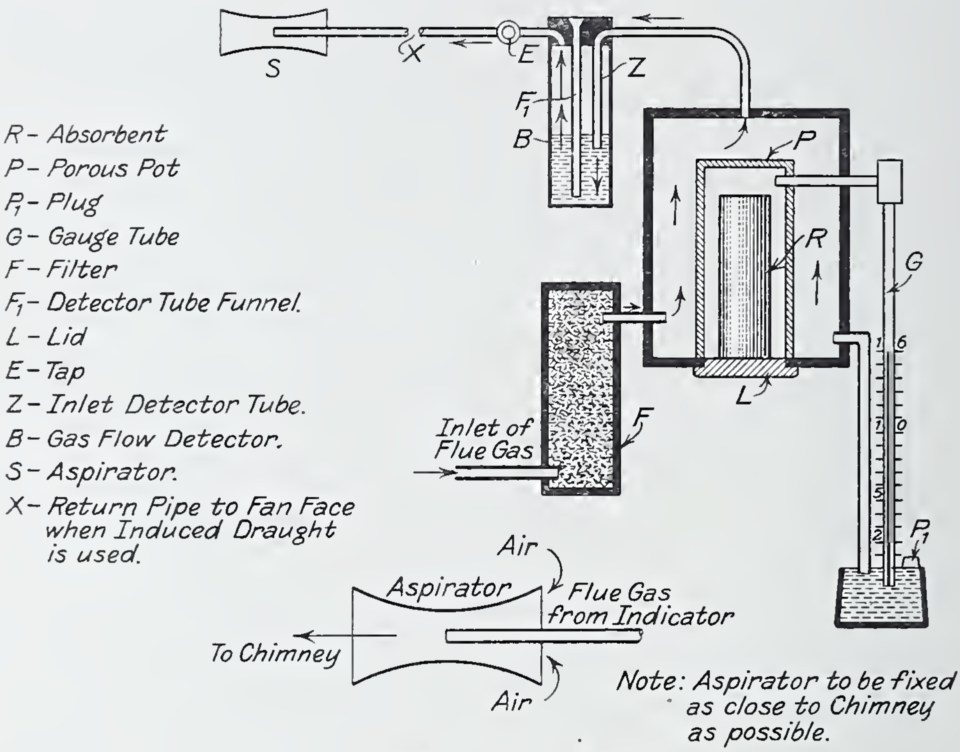


FIG. 195.—THE W.R. CO_2 INDICATOR.

CO_2 apparatus in this country. It is made in three types—(1) as an indicator, (2) as a recorder, and (3) as a combined indicator and recorder.

The operation of the indicator, which is illustrated in Fig. 195, may be briefly described as follows :—

A small aspirator S is used to draw a sample of the gases continually, which, following the course indicated by the arrows, passes through the filter F, after which it enters a chamber containing a porous pot P, which is charged with a dry absorbing medium R for CO_2.

This chamber and porous pot are connected by means of two vertical pipes or tubes with a water vessel. The difference in pressure between the gas in the outer chamber and that in the porous pot—due to the absorption of CO_2—causes the water to rise in the pipe G connecting the porous pot with the water vessel B, which acts as a gas flow detector, the flow of gas being shown by continuous bubbling

through the water in this vessel. A graduated scale attached to this pipe indicates the percentage of CO_2.

While the many types of CO_2 apparatus now available represent a great advance upon the various instruments of continental origin introduced in this country some twenty years since, and while generally speaking, they leave but little to be desired in so far as accuracy is concerned, yet it is essential that apparatus of this kind should receive reasonable care and attention, and the operating and maintenance instructions should be rigidly observed.

Draught Gauges.—The most efficient draught for every boiler is that which will enable the demand for steam to be met, while at the same time showing the highest percentage of CO_2 in the gases, with an absence of CO.

Such draught conditions can only be determined and maintained by the use of a draught gauge in conjunction with flue gas analysis, and preferably also with a knowledge of the temperature of the exit gases to the chimney. In connection with the majority of steam boiler installations in this country, the only information available concerning the draught is that it is good, bad or variable as the case may be. As to whether it is the most efficient draught for the existing requirements, usually nothing is known. Bad draught or bad coal have been termed " the fireman's standing alibi "—the ever-ready explanation for reduced pressure or shortage of steam—but in justice to this oft maligned individual, it must be admitted that those primarily responsible have as a general rule failed to interest themselves either in the question of draught efficiency, or in the quality, suitability or value of the coal used.

It is no more possible to determine the most efficient draught without a draught gauge than it is to determine the steam pressure and water level without the use of the necessary gauges.

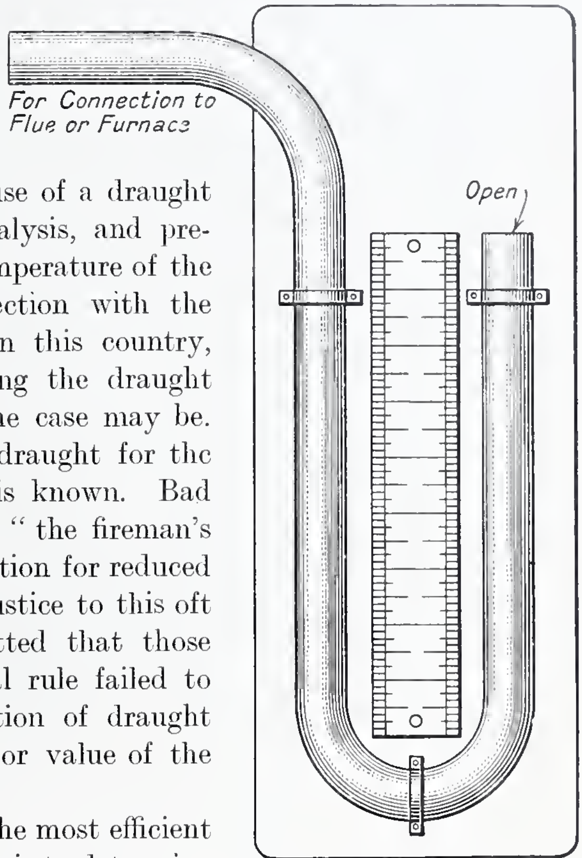


Fig. 196.—The U Tube Draught Gauge.

The U tube.—The simplest form of draught gauge is the U tube, as illustrated in Fig. 196, which indicates the difference in pressure between the point to which it is connected and the atmosphere.

The difference in the water level in the two legs of the tube shows the draught on the scale, indicated in inches and tenths of inches of water.

For all ordinary purposes and for periodical use in connection with small steam plants, this inexpensive and simple draught gauge will be found quite suitable.

Dial Draught Gauges.—For use at the front of boilers or at other convenient

points, so that the draught indication may be under continuous observation; for the guidance of the attendant the dial type of draught gauge is very convenient.

Among the various dial draught gauges on the market are the Bristol, Sarco, Cambridge, and Simmance's Dead Beat Indicator, some of which are also equipped with continuous recording mechanism. Gauges of the dial type are also made to indicate the difference in pressure between two points, for instance, above and below the grate of a furnace, or at the combustion chamber, the boiler damper, or at the inlet and outlet of the economiser flues. As these gauges are usually provided with

Fig. 197.—The Cambridge Dial Draught Gauge.

a large dial and a long scale, small variations in draught may be readily observed at a distance.

The Cambridge Dial Draught Gauge.—This gauge, which is illustrated in Fig. 197, is of the flexible diaphragm type. For single point reading instruments the front of the diaphragm is open to atmospheric pressure. The diaphragm is controlled by a spring, and connected by a rack and pinion movement to a pointer which moves over the dial. All movements of the diaphragm due to pressure variations give rise to corresponding movements of the pointer.

The Cambridge Draught Recorder.—Another type of Cambridge draught gauge is illustrated in Fig. 198; this is a recording instrument giving the measurement of draught or pressure up to the maximum range across the chart of 8 in. of water.

This gauge operates on the hydrostatic principle, the pen arm being carried on a German silver float, partially submerged in water, contained in an outer vessel, the water being covered with a layer of oil to prevent evaporation.

A tube connected to the point at which it is desired to obtain the measurement enters the lower part of the instrument, and projects into the space below the float. Variations in the pressure will therefore cause a rise or fall, and the pen traces out a record of the pressure variations on the chart covering the revolving drum. The chart drum makes one revolution every twenty-four hours.

A removable dust proof glass cover with brass top protects the chart drum, driving clock and pen.

Fig. 198.—The Cambridge Draught Recorder.

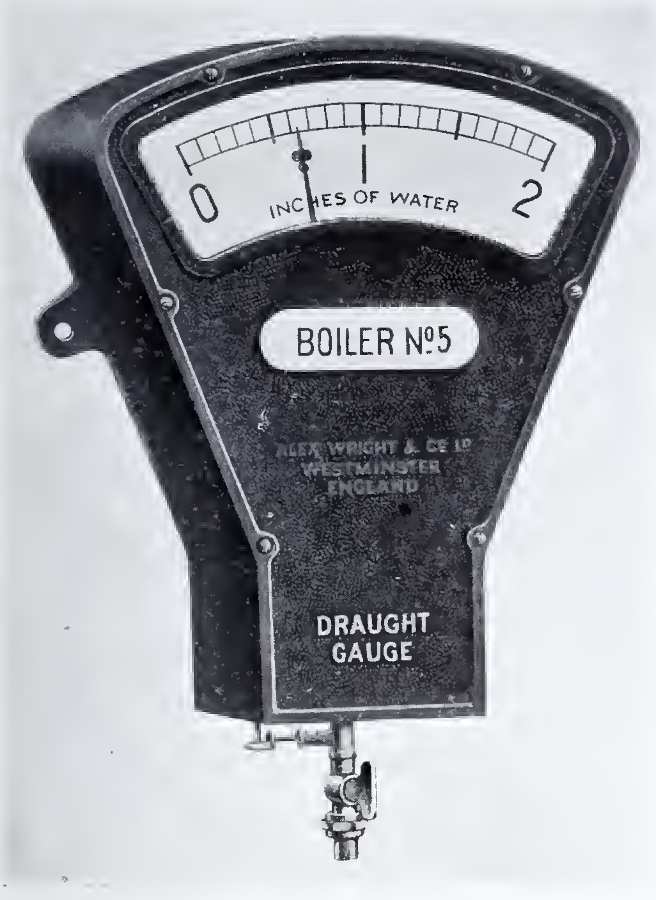


Fig. 199.—The Simmance Dead Beat Indicator Draught Gauge.

Simmance's Dead Beat Indicator.—This well-known draught gauge, which is illustrated in Fig. 199, is of the diaphragm type. It is provided with a large legible dial, which may, if desired, be illuminated. The gauge is provided with a two-way cock, the turning of which vents the gauge and brings the pointer to zero.

Y

The Usco Draught Indicator.—The Usco draught indicator is a novel type of draught gauge, providing for the simultaneous reading of draught pressures at three points.

This instrument is designed on the hydrostatic principle and gives continuous reading without mechanism. The essential element in this apparatus, the measuring gauge, consists of an open-ended glass tube supported from a rubber cork, fitted on

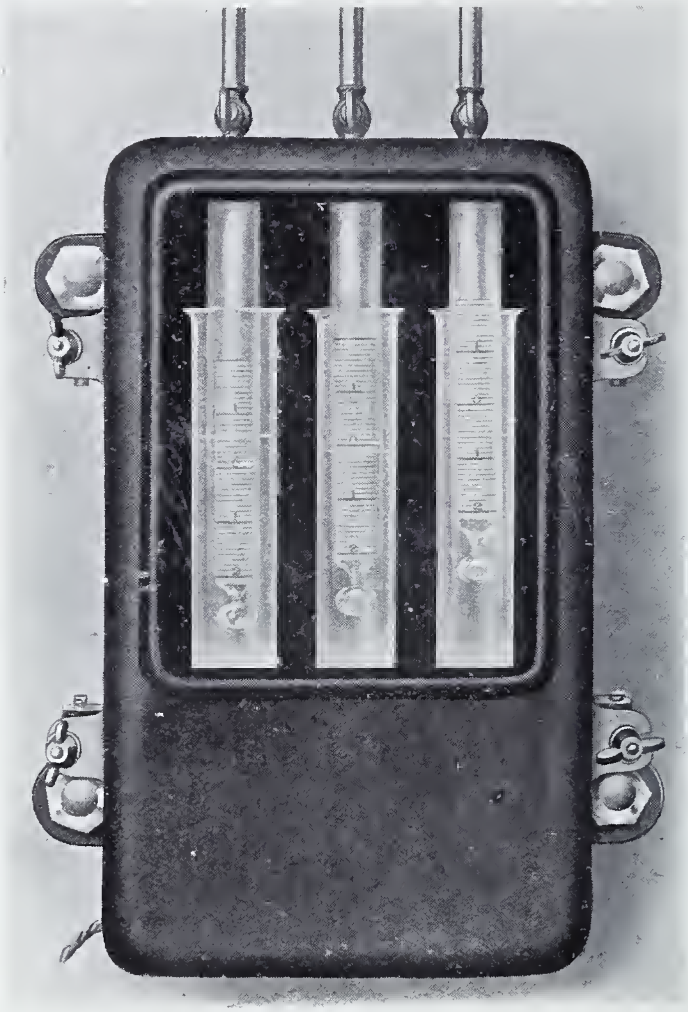


FIG. 200.—THE "USCO" DRAUGHT INDICATOR.

an extension of a two-way cock on the top of the case. Outside of this tube is another tube closed at the lower end.

In the interior of the open-ended tube is a float, in which is a scale, marked in inches and tenths, this float being so adjusted that the level of the water is at the zero marked on the scale, which is extended above and below this point.

Thus the difference of levels in the water, whether due to pressure or a partial vacuum, can be read directly by the position of the surface of the annulus against the scale without calculations or adjustment.

The three gauges are substantially mounted in a strong dust proof case, which, to facilitate reading, may, when necessary, be internally illuminated.

The Usco draught indicator is illustrated in Fig. 200.

Differential Draught Gauges.—The differential draught gauge just described is of the vertical type, other differential draught gauges of the inclined type—a type which is now extensively used in the United States—are illustrated in Figs. 201 and 202.

Hay's Differential Draught Gauges.—A good example of the differential type is Hay's draught gauge, see Fig. 201. This gauge is arranged for indications at two points, while in Fig. 202 is shown the most recent development in this type of draught gauge, providing for separate connections to six points individually controlled, with readings all on the one instrument.

With these gauges a light mineral oil is used instead of water for indication,

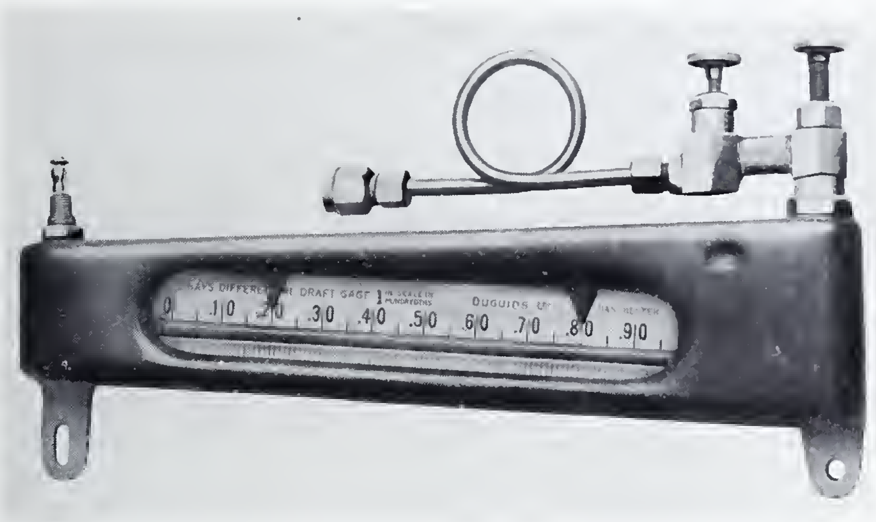


Fig. 201.—Hay's Differential Draught Gauge.

the oil being coloured a brilliant red. For bringing the oil quickly and accurately to the zero mark on the indicating scale, the use of a special levelling micrometer attachment, designed by the makers of the gauge, is recommended.

These gauges are of very robust construction, easily readable and in every respect suitable for boiler house conditions.

Hay's Vernier Draught Gauge.—For very close and accurate readings the Vernier draught gauge constructed on the U-tube principle is exceedingly useful. It may be held in the hand while readings are being taken, the slidable Vernier scales reading to one-hundredth of an inch water gauge.

Temperature Indicating and Recording Instruments.—Incredible as it may appear, in the average boiler house nothing is known as to the existing temperature at any point in the flues. The chimney loss, serious as it so often is, appears to be accepted as a necessary evil, the extent of which is not generally appreciated.

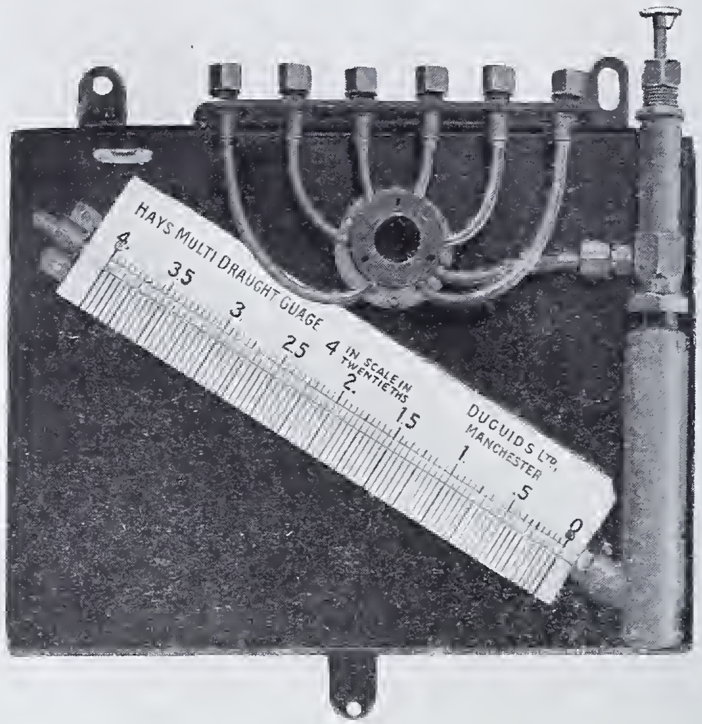


FIG. 202 (part of).—HAY'S MULTI-POINT DRAUGHT GAUGE.

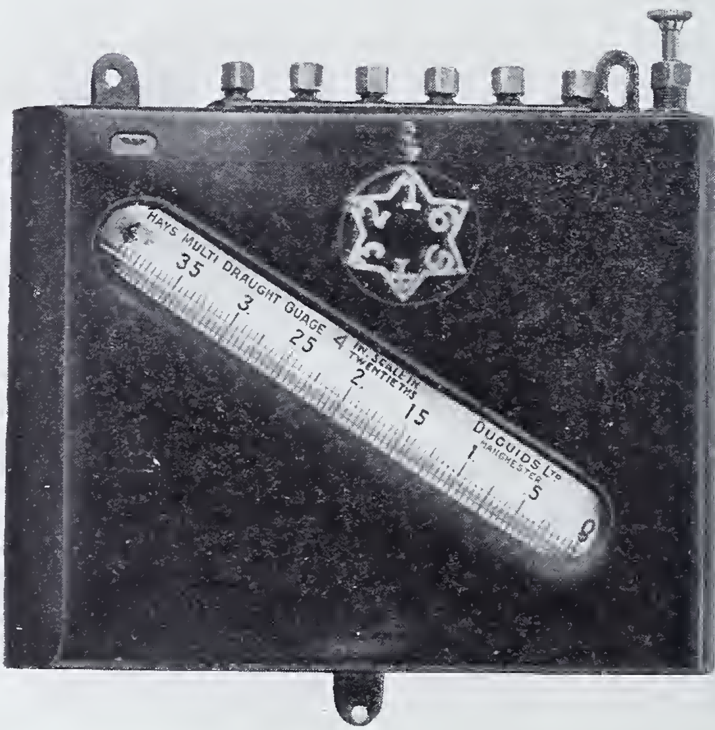


FIG. 202 (part of).—HAY'S MULTI-POINT DRAUGHT GAUGE.

If the installations of economisers or superheaters is contemplated, usually no information as to the available temperature is obtainable, and the firm or firms tendering must either assume a temperature, or alternatively ascertain the available temperature for themselves. Having in mind that the loss of sensible heat carried away by the chimney gases is the heaviest of all losses in steam generation, and is usually the loss which offers the best chance for reduction, it is to be regretted that its extent in the average case, and what it involves in avoidable waste of fuel, is not even dimly realised.

Unless means are provided for the determination of the extent of this loss, little is likely to be done towards remedying it. For this reason, and because an

Fig. 203.—The Cambridge Thermo Electric Indicator.

accurate knowledge of existing temperatures is necessary in any effective steps to eliminate fuel waste, and to ensure efficient working conditions, that the provision of one or more pyrometers is an essential part of the boiler house equipment.

Pyrometers.—The pyrometers which are now most extensively used in modern boiler house practice are electrical, and either of the thermo-electric or resistance types.

Pyrometers of the thermo-electric type can be used to measure temperatures up to 1400° C., and are very convenient and accurate for the determination of gas temperatures. These pyrometers depend for their operation upon the fact that if wires of two dissimilar metals are joined at their ends to form an electric circuit, and one junction is heated, an electromotive force is set up, giving rise to

a current in the circuit which can be measured on a suitable galvanometer. Since the magnitude of the electromotive force depends upon the difference between the temperature of the hot and cold junctions, the galvanometer, which may be either of the indicating or recording pattern, can be calibrated to give readings directly in degrees of temperature.

The type of thermo couple used will depend upon the temperatures to be measured, and the conditions under which the couple will have to be employed. Rare metal couples made of platinum and an alloy of platinum and rhodium have the longest life, particularly at higher temperatures, and are the only type suitable for temperatures above 1100° C. which amply cover all possible boiler house requirements. Base metal couples, which are much less expensive, are quite satisfactory for temperatures below 1100° C.

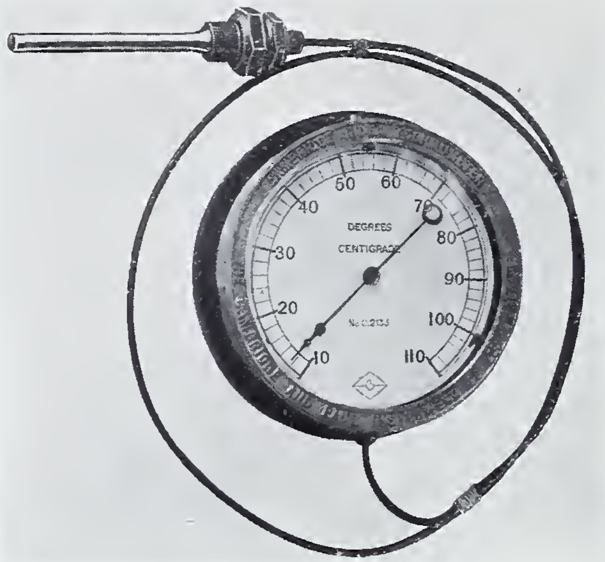


Fig. 204.—The Cambridge Index Thermometer. Mercurial Type.

The protection provided for the thermo couple wires depends upon the temperature to be measured and other conditions of use. For temperatures above 800° C. a porcelain tube is used, protected by a steel sheath left open at the lower end, to ensure rapid responses to changes in temperature. For temperatures below 800° C. a steel sheath is used with a closed end, if the temperatures do not exceed 600° C., or for temperatures between 600° and 800° C., two steel sheaths are fitted.

Cambridge Thermo-electric Indicator.—In Fig. 203 is illustrated the type of thermo-electric indicator which is now extensively used in boiler houses. The electrical resistance type of instrument which is more usually known as a distance thermometer, depends for its operation upon the fact that the electrical resistance of the platinum wire changes with the temperature, according to a well-known law. The resistance of the thermometer coil is tested by a modification of the Wheatstone

Bridge method, the thermometer being included in one arm of the bridge, the other coils of the bridge are arranged inside the case of the indicator.

Any alteration or resistance in the thermometer due to change of temperature will cause a change in the galvanometer deflection, and the instrument can be calibrated directly in degrees of temperature. These instruments have a range of from 330° to 1000° F., and are made both for indication and recording.

The thermometers consist of coils of platinum wire wound spirally on porcelain spools, and protected according to the conditions under which they will be used. Although mounted in various ways to suit different requirements, the thermometers

FIG. 205.—THE CAMBRIDGE RECORDING THERMOMETER, MERCURIAL TYPE.

are all interchangeable, they are strongly made, and are not subject to breakage. The so-called platinum bulbs are usually 50 mm. long and 11 mm. in diameter. It is important that the whole of the bulb be subjected to the temperature it is desired to measure.

Cambridge Index and Recording Thermometers, Mercurial Type.—Thermometers of these types illustrated in Figs. 204 and 205 are capable of working continuously at temperatures ranging from 40° to 1000° F. The principle of operation is as follows:—The steel bulb of the instrument which may be plain, as in Fig 205, or with screwed fitting, as in Fig. 204, is connected by means of steel capillary tubing to a special form of Bourdon steel spiral. The whole system is filled with mercury, and changes of temperature of the bulb give rise to corresponding changes of

pressure in the system, and consequently to small movements of the Bourdon spiral, which are magnified and recorded or indicated by the usual pen or pointer mechanism. The flexible steel capillary tubing may be of any length up to 50 ft.; where only a short length of capillary tubing is required, this may be enclosed in a rigid stem if desired.

An electric alarm attachment, by which a bell is rung if the temperature exceeds

FIG. 206.—THE FÉRY RADIATOR PYROMETER.

or falls below a certain predetermined point, may be fitted to these thermometers.

The Féry Radiation Pyrometer.—For the measurement of very high temperatures, as for instance furnace temperatures, the best apparatus is the Féry radiation pyrometer, which is illustrated in Fig. 206.

With this apparatus a telescope is focussed on the hot body, the heat rays being received on a concave mirror and brought to a focus on a small thermo

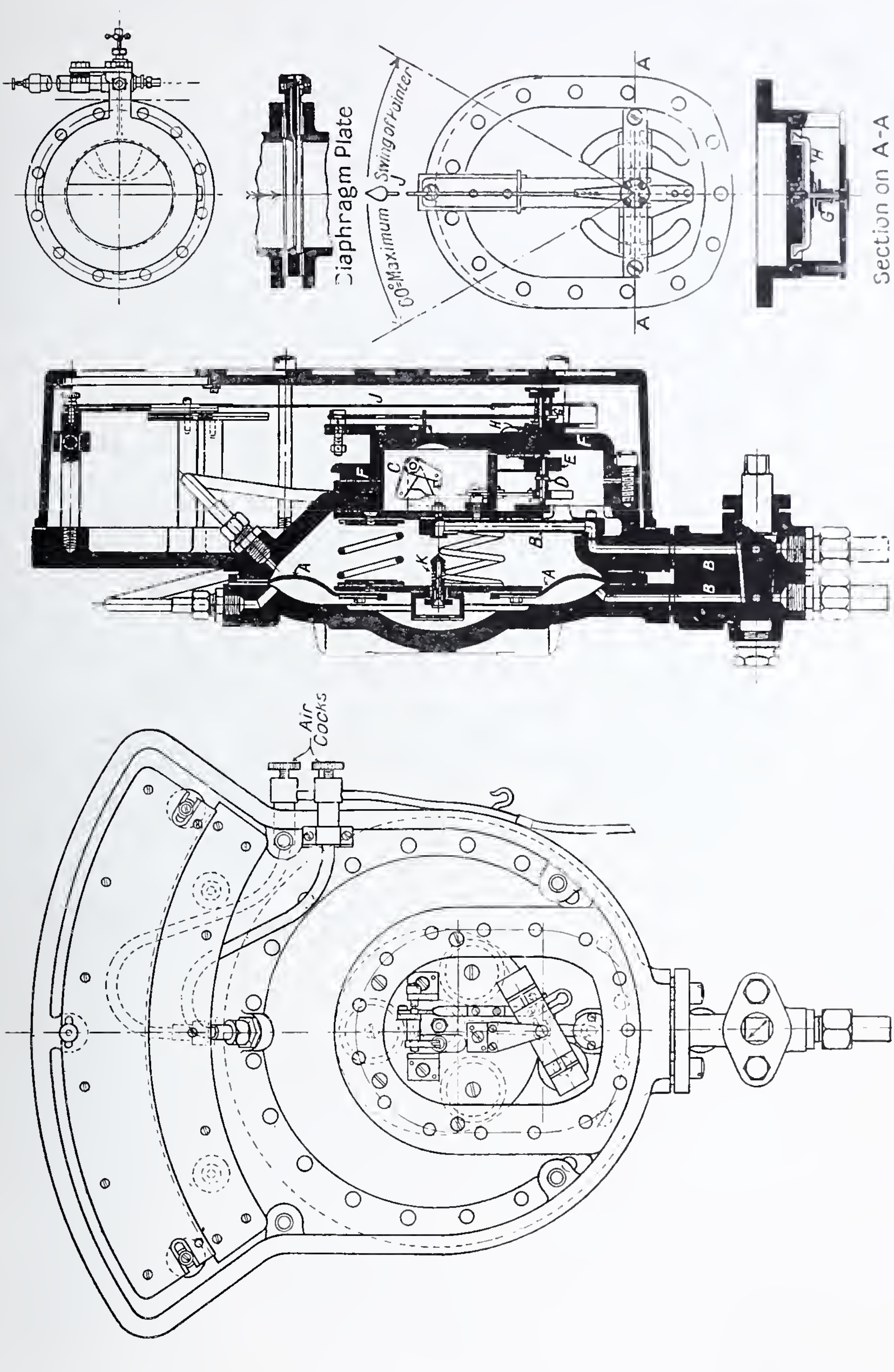


Fig. 207.—Kent's Steam Flow Indicator.

couple. The electromotive force produced by the consequent heating at one junction of the thermo couple is measured on an indicating or recording galvanometer, calibrated to give direct readings in temperature.

For ordinary boiler house operation, it is unnecessary to measure the furnace temperature, and useful as this instrument is, in boiler house practice it can have but a very limited scope.

Steam Meters.—Meters for the continuous indication of the flow of steam

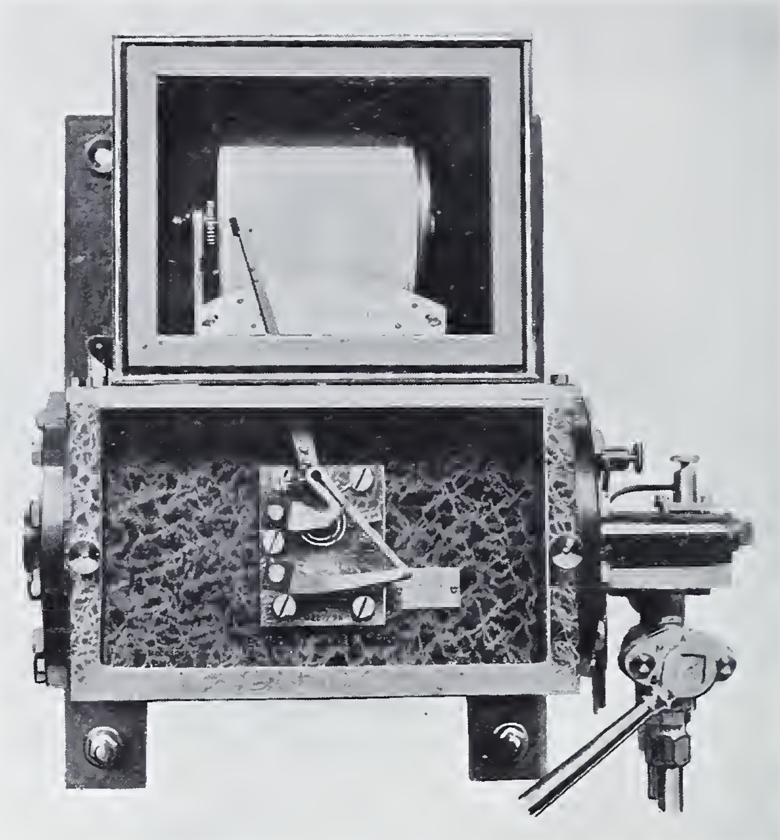


Fig. 208.—Kent's Non-pressure Corrected Type of Steam Flow Recorder.

through steam mains or branches are now being widely used in electric power stations, and also by other large steam users.

When a steam flow meter is used in connection with each boiler, a convenient means is provided for determining and regulating the output of individual boilers. Steam meters are made in three types: (1) The rate of flow indicator, for showing the amount of steam passing at any time; (2) the recording type, giving a diagrammatic chart of the flow of steam continuously, also showing variations in the flow; and (3) the counter type, giving, in addition to the rate of flow at any time, the total quantity of steam passed, by means of a counter device. If desired the functions of all three types may be combined in a single meter.

Kent's Steam Meter.—Kent's steam meter, which is made in all three types as mentioned above, or of the combined type, is on the differential pressure principle. A carefully calibrated orifice is placed in the pipe line, pressure tubes on either side communicating with the indicating or recording instrument.

The function of the orifice is to establish a difference in pressure on opposite sides of the plate, the size of the orifice openings depending upon the maximum velocity of the steam in the pipe, which has to be measured. The rate of flow indicator depends for its action upon the movement of a rubber diaphragm A, under

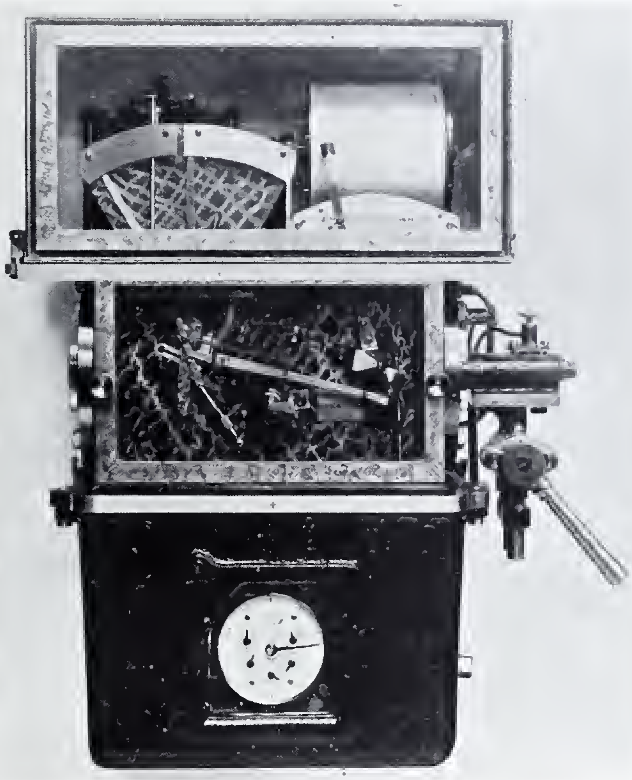


FIG. 209.—KENT'S PRESSURE CORRECTED TYPE OF STEAM FLOW RECORDER WITH INTEGRATOR.

the influence of variations in the difference of pressure on its opposite faces. The faces on opposite sides of the diaphragm A are in communication by means of the passages BB with the sides of the orifice plate in the steam pipe. A set of three coiled springs controls the movement of the diaphragm, which is communicated to the spindle D through rods, and a bell crank C. This spindle carries a powerful magnet E. Outside the case and in line with D, there is another spindle G, carried in jewelled bearings, to which is attached an iron armature H and the pointer J. In this way the movement of the diaphragm is transmitted to the pointer, without it being necessary to make a watertight rotating joint, an exact register of the most minute movements being obtained. The graduations of the dial over which the

pointer works can be made to show the quantity of steam passing at any predetermined pressure and temperature.

The instrument described, which is shown in Fig. 207, is the simple rate of flow indicator, not corrected for variations in steam pressure, and steam temperature

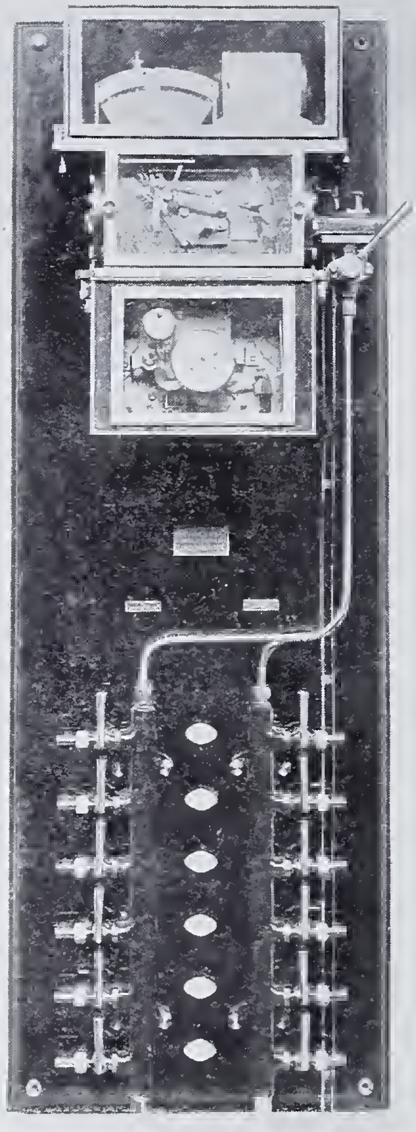


Fig. 210.—Kent's Steam Flow Recorder, mounted on a Six-way Switchboard.

(when indicating superheated steam). The recording instrument and also the counter type of instrument are both made with or without automatic pressure correction gear.

In Figs. 208 and 209 respectively are shown Kent's non-pressure corrected

type of steam flow recorder, and the pressure corrected type of recorder with integrator.

With a view to encouraging the more extended use of steam flow indicators in connection with individual boilers a new steam flow indicator of a cheaper type has recently been introduced by Messrs Kent. This instrument is similar in principle to that already described, its action depending upon the differential pressure set up by a calibrated orifice plate in the steam main, which acts upon a spring controlled diaphragm within the body of the meter, the motion of the diaphragm being communicated through a gland to the pointer. If desired this indicator may

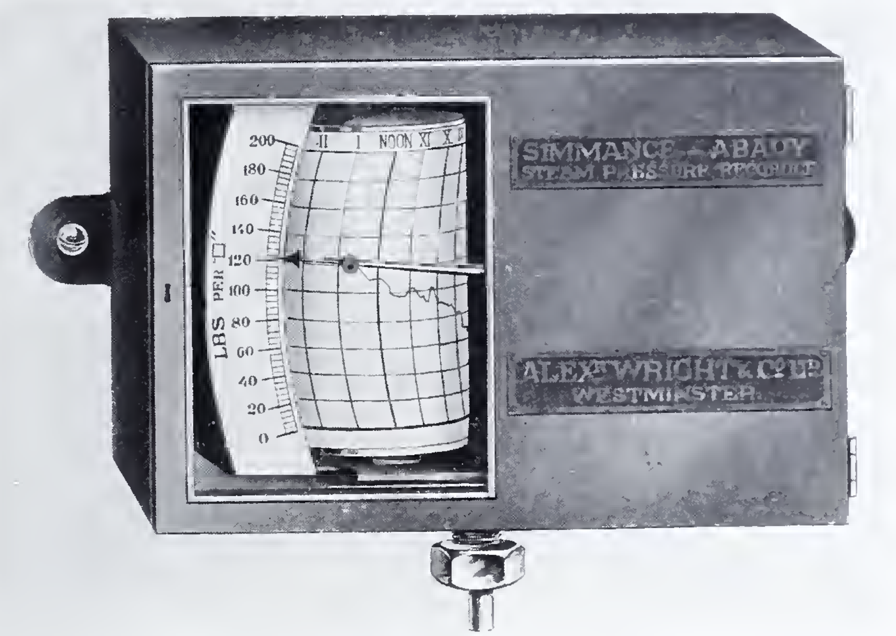


FIG. 211.—WRIGHT'S COMBINED INDICATING AND RECORDING STEAM PRESSURE GAUGE.

be used with a switchboard, and connected to a number of boilers as shown with the steam flow recorder illustrated in Fig. 210.

Steam Pressure Recorders.—For the continuous recording of the steam pressure, either in connection with individual boilers or a range of boilers, the steam pressure recorder affords a continuous check upon operation, and as such is exceedingly useful. Fig. 211 illustrates a combined indicating and recording steam pressure gauge made by Messrs Alexander Wright & Co., Ltd.

The Cambridge Steam Pressure Recorder.—The Cambridge steam pressure recorder is illustrated in Fig. 212, the construction being as follows :—

A Bourdon spiral is connected to a union by means of which it can be attached to a copper tube taken from the position at which the temperature is to be measured. The movements of the Bourdon spiral are communicated to a pen arm, which moves

over a circular sheet graduated to show pressures or vacua, and rotated by a clock mechanism.

These recorders are made for any range of pressures up to 1000 lbs. per square

Fig. 212.—The Cambridge Steam Pressure Recorder.

inch, and are mounted in dust-tight metal cases, with nickel plated fronts, and provided with a lock and key.

CHAPTER XIV

BOILER HOUSE CONTROL AND THE TRAINING OF BOILER FIREMEN

HAVING in mind the importance of the human factor in the firing of steam boilers, it is a matter for regret that greater facilities have not been provided for the education and training of firemen. Efficient operation of plant is necessarily based more upon the human element than any other factor. The most complete and satisfactory plant, installed regardless of expense, will only show a working efficiency directly proportionate to the efficiency of its operation.

To a large extent unfortunately the firemen has been left severely alone, his method or lack of method has received but scant attention. Too often all that is looked for is a sufficient supply of steam at the desired pressure, apart from any other consideration.

Not only have the training facilities provided for firemen been altogether inadequate, but there has been and still is a disposition to regard boiler firing as unskilled work, and the boiler house as a part of the establishment where money can be saved by employing unskilled or casual labour.

Without training facilities, without any general recognition that efficient firing demands experience and skill, without much suitable or helpful literature,[1] to a large extent the man who has taken up boiler firing as an occupation has had to laboriously work out his own salvation, usually at a very heavy cost to his employers.

The steam user, for the most part unfortunately unconcerned with questions of fuel economy, and mainly desirous of having an ample supply of steam, has to a very serious extent failed to discriminate between the man who is merely able to shovel coal and a fireman.

The well-known fact that the thermal efficiency of hand fired boilers is usually very low, is mainly due to the very extensive employment of unskilled labour, and also the general lack of organised and effective control.

Not only are firemen responsible for a grievous waste and inefficiency inasmuch as they are directly concerned with the handling of the fuel, and the operation of furnaces, but those who fail to supervise, control, or even to intelligently interest themselves in boiler house operation, are primarily to blame for the existing conditions.

The vital importance of effective supervision and control was very clearly

[1] An excellent handbook for firemen was published in 1920, see "The Fireman's Handbook and Guide to Fuel Economy," by Charles F. Wade, A.M.I.Mech.E., A.M.I.E.E.

recognised by H.M. Fuel Research Board, who in their report for the years 1918 and 1919,[1] made the following observations :—

"Any such programme should deal first with the prevention of mere reckless waste, which invariably tends to develop in all works, unless there is continuous skilled control. Even in works which are in other respects well managed, actual waste of coal at furnaces, and steam at every point in a distributing system, always grows rapidly but unnoticed, unless it is the duty of some one overseer to watch the consumption, and to keep daily records of coal received and heating work done. . . . It cannot be too strongly urged that the establishment in every large works of an organised fuel control, is the only sound foundation on which to build more revolutionary or further reaching methods of fuel economy."

In some of the larger works in this country, and to a far greater extent in the United States, boiler house or combustion engineers have been appointed, whose responsibility is limited to the selection or purchase of all coal, as also the supervision and control of the whole of the plant and labour in any way concerned with its handling and utilisation.

This would appear to be the only practical method by which the existing conditions can be substantially improved, and it is not too much to say that in the case of every works or factory using not less than 100 tons of coal per week, the introduction of such a system of control would effect a very considerable saving.

It is assumed that in connection with any such appointment the boiler house engineer would be given complete control, that he would be permitted to at any rate select the fuel to be used. as also the apparatus for its utilisation, and that he would engage and have authority to dismiss the boiler house staff. He would keep close and continuous records of operation, and would be required while meeting all demands for steam, to justify his appointment by economies effected, and maintained, in boiler house operation, which would cover not only the actual cost of the coal used, but every contingent cost in its handling and utilisation. The boiler house would to all intents and purposes be treated as a separate undertaking—a factory producing steam.

It is becoming increasingly evident that the old system of making one engineer responsible for the production and use of steam, as also for every trivial detail in plant maintenance, is under existing conditions an impossible system.

Under any satisfactory system of boiler house control on the lines indicated. in the careful selection of the boiler house staff cheap labour as such would have no part. Greater intelligence, experience, and interest, would be required and paid for. A better class of men would be attracted to work which would be regarded as demanding not only muscle but brains. The status of the fireman would be greatly improved, to the advantage of both employer and employee.

To the steam user such a system offers an improved thermal efficiency, a considerable economy, not only in the cost of fuel but in plant maintenance, an increased efficiency in labour, and greater reliability in operation. These are all points which emphasise the importance of divided control, to the extent of making one engineer

[1] See Reprint of H.M. Fuel Research Board, 1918-1919, page 4.

responsible for the efficient generation of steam, and another engineer responsible for its efficient use.

No one has a greater admiration for the works' engineer than the author, and while in this country we doubtless have some of the best qualified works' engineers in the world, their training has been such that they have not had opportunities of concentrating or specialising in fuel and combustion problems, while the multifarious nature of their duties too often prevents them from devoting close attention to the boiler house, *where, if there is to be any organised and effective economy, it must begin.*

Many works' engineers are unable to obtain the plant they want, and they are also compelled to accept and utilise labour of a grade which they do not want, because it is supposed to be cheap.

That the system of undivided control has been and is unsatisfactory is shown by the low thermal efficiency of steam generating plant, the wasteful use of steam, the appalling avoidable waste of industrial coal, the inefficiency of labour, and the high cost of maintenance.

Manufacturers of boiler house plant, such as, for instance, mechanical stokers, furnaces, and coal and ash handling plant, are usually required to give stringent guarantees as to performance. To a serious extent such plant is operated by unskilled labour, too often with little or no effective supervision or control, with the result that well designed and expensive plant is not operated to advantage, average working results are disappointing, the plant is unreliable, and the cost of maintenance excessive.

For these conditions it is not usually recognised that unskilled labour and lack of control are primarily responsible ; instead the manufacturer of the plant is blamed, and the plant is condemned as useless. In the stress of competition manufacturers of boiler house plant have given, and still continue to give, guarantees as to performance without due regard for the conditions under which the plant has to operate. There has been an unfortunate disposition upon their part to ignore or belittle the importance of skilled labour in the boiler house, and to no small degree have they by their attitude contributed to the present position.

The high cost of maintenance of mechanical stokers with internally fired boilers is primarily due to neglect, and not to inherent defects or weakness in design or construction. Similarly, the unsatisfactory results so frequently obtained are mainly due to improper operation and lack of adjustment, without adequate supervision. The only concern is to maintain the required steam pressure, which is often accomplished with much unnecessary and misdirected energy, and with little or no regard for cost.

In a carefully supervised boiler house with proper operation, and regular and systematic inspection and maintenance of all plant, it is no exaggeration to state that in many cases the cost of maintenance could be reduced to the extent of 50 per cent., to say nothing of the great advantage of ensuring the utmost reliability and continuity in operation.

Under existing conditions not only is the position of the works' engineer frequently exceedingly unsatisfactory, but the apathy of the proprietor, or directors,

and their attitude towards the use of unskilled labour is to a serious extent responsible for their constant complaint concerning the cost of fuel and maintenance.

So long as men are employed who are merely able to throw coal through a fire door opening, or into mechanical stoker hoppers, men with no experience or conception of what is involved or required in the efficient and economic use of fuel, it is hopeless to look for any material improvement.

The author is not entirely opposed to the use of unskilled labour for firing; on the contrary it is realised that the untrained and unskilled man, with no bad habits or preconceived ideas, in short, with nothing to *unlearn*, can often be so trained as to become an expert fireman. What is so generally lacking is the necessary training, advice, and supervision. The boiler house, sometimes termed the "stoke hole," is treated as a place to be avoided, or but rarely visited, the centre of dirt and discomfort.

In the Final Report of the Committee on Smoke and Noxious Vapours Abatement, 1921,[1] attention is thus directed to the necessity for the training of firemen :—

"It is generally admitted that unskilful and negligent stoking is responsible for a considerable amount of unnecessary smoke which is emitted.

In some cases municipalities, smoke abatement societies, and private firms have instituted technical classes for the instruction of stokers, but generally speaking too little attention has been paid to the matter.

We have been informed by stokers themselves that they would welcome instruction that would enable them to acquire increased knowledge and ability to perform their duties more efficiently. We have heard of classes which have met with great success, and we think it would well repay manufacturers and local authorities to give more attention to the training of stokers. The manufacturer would be benefited by the economy in fuel which would result from better stoking, and the community would be benefited by a reduction in the amount of smoke emitted. Stoking should be regarded as a trade, skilled and paid as such."

Having in mind that industrial works contribute heavily to local and education rates, it would appear to be a sound policy for technical education authorities in important industrial areas to actively take in hand the provision of technical instruction in firing and the use of fuel. Many subjects are now taught in technical institutes for the benefit of a favoured few at very considerable cost, the necessity for, and importance of which, cannot in any sense be compared with the national importance of efficiently using coal.

It has been argued that the training of firemen is not the legitimate concern of local technical education authorities, and that it should be left to the manufacturer. It is just as reasonable to argue that all technical instruction should be the responsibility of the various industries concerned. The purpose of a technical institute is to provide the best technical instruction possible, always having in mind the nature of local industries and local industrial needs. In all important industrial centres a real want would be met in the provision of the best possible technical instruction in boiler firing, and there is but little doubt that manufacturers would

[1] See Final Report, Committee on Smoke and Noxious Vapours Abatement, 1921, page 75.

not only encourage such provision, but would also render much practical assistance towards ensuring its success.

In order to be effective such instruction must be both theoretical and practical, and the course should embody elementary instruction in the principles of combustion, as also methods of firing, both by hand and machine, smoke prevention, the composition of the gases, and the use and object of essential boiler house instruments. The course should cover at least two sessions, elementary and advanced, and a certificate of proficiency should be awarded to those who complete the course and who are successful in satisfying the examiners.

If such a scheme were generally adopted in industrial areas, in a comparatively short time there is but little doubt that a considerable proportion of firemen would hold certificates, the status would be materially improved, and qualified men would gradually displace untrained men. By combination, boiler firing would of necessity be quickly regarded as a skilled trade, as it unquestionably should be.

While very encouraging results have been obtained by the individual efforts of some engineers and employers, the only hope for improvement upon any considerable scale would appear to be on the lines discussed. Mr W. M. Miles, A.M.I.Mech,E., F.C.S., of Sheffield Corporation Electricity Department, stated in a paper[1] read before the Incorporated Municipal Electrical Association, that "as the result of a series of lectures which he delivered to firemen and firewomen during the War, there was a gradual increase in the boiler efficiency of from 68·01 to 73 and 74 per cent."

Early in 1920 The South Metropolitan Gas Company, London, started a boiler house school for firemen, with a view to providing a complete practical training course. Every boiler fireman had to undergo a course of about two weeks' practical training in feeding and clinkering boiler fires.

One boiler house was equipped with all the necessary apparatus for the measurement of fuel, water, and draught. CO_2 apparatus was also installed in order to continuously determine the composition of the gases of combustion at various points in their passage.

The boilers in this house were kept on their ordinary load, so that all ascertained results were those obtained under ordinary or normal working conditions, as distinct from test conditions. Each delivery of fuel to the boiler house was sampled and tested, in order to determine the calorific value and percentages of ash and moisture.

Careful records were kept of each day's operations, and it was reported that as the result of the training there was a distinct and steady improvement in working efficiency. It was found that the men took a keen interest in the results obtained, and readily admitted that their work was less arduous.

The enterprise of The South Metropolitan Gas Company in thus training their firemen is to be commended, particularly when it is borne in mind that the fuel used is not an expensive coal, but coke breeze. The training given has served to emphasise this very important point—that the man who uses his brains as well as his shovel has less work to do than the man who wastes fuel.

[1] See *Proceedings of the Incorporated Municipal Electrical Association*, July 20th, 1921.

An untrained and inexperienced fireman must inevitably work harder, owing to misdirected effort, than the trained man who is able to evaporate an equal weight of water in a given time with considerably less fuel.

Training is essential because under such conditions as now obtain the use of common sense is of vastly more importance and value than misdirected muscular energy. Apart, however, from the question of training, it is very desirable to provide some incentive in order to encourage interest and sustain effort. Many bonus systems have been tried, but it cannot be said that any one of them has been altogether successful under the more or less varying conditions which are usually experienced. No bonus system has yet been evolved which, under all conditions, has worked out fairly to both parties. Systems have been tried which have, under certain conditions, operated unfairly against the employee, other systems have been abandoned because it was discovered that they were open to abuse.

It is of the utmost importance to secure and retain the confidence of the fireman. To this end no instrument or apparatus installed in the boiler house should be permitted to remain a mystery to the fireman. So far as is practicable he should be instructed and brought to realise the principle of the apparatus, the object of its provision, and the improved results which it is intended to make possible.

It is only along such lines that co-operation and interest can be secured. If the full value is to be obtained out of such apparatus as may be installed, this will not be accomplished by allowing any impression to exist that a particular instrument is merely a "tell tale," but rather by satisfying the fireman that the improved results which may be obtained will be to his advantage, as well as to the advantage of all concerned.

If, from the point of view of smoke abatement, the training of firemen is important—and no one will dispute this—then it may be said that a complete change in the existing methods is also of importance from the standpoint of efficiency in steam generation and also coal conservation.

Until it is clearly recognised that training is essential, and until steps have been taken to provide suitable training, there can be no considerable advance in the efficient operation of steam boiler installations.

In advocating improved methods of steam generation, and the adoption of apparatus and accessories for reducing or eliminating avoidable waste, it is necessary to emphasise the importance of new men as well as new methods.

If a more extended use of low grade fuels is to be made the questions of effective control and the employment of skilled firemen must be regarded as essential factors. Such fuels will not be used upon any considerable scale without close supervision, and the employment of skilled labour. The unskilled and incompetent will continue to insist that steam cannot be maintained with any fuel but the best, no matter what apparatus is provided.

There are signs that in the near future facilities will be provided in some of the provincial industrial centres for the training of firemen. The question is now arousing unuusal interest, and it is likely that, pending legislation in regard to

smoke prevention, it will not be without effect in compelling those responsible to take action.

When it is borne in mind that in a country such as Holland, having but a comparatively small industrial coal consumption, instruction for firemen has been provided for the past fifteen years by Government order, it must be admitted that we have been tardy in our recognition of the essential condition for boiler house efficiency—skilled operation.

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